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THESIS

AIRBORNE UBIQUITOUS SURVEILLANCE AND MONITORING NETWORK

by

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September 2004

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The thesis research examines the emergence of wireless technology as a pragmatic baseline supporting the goals of the Department of Defense developing towards Network Centric Forces. Increased international attention to the field of surveillance has developed parallel to the desire to interconnect all possible friendly forces in military operations and the Global War on Terror (GWOT).

Ubiquitous surveillance is accomplished by prototyping a network node that is then integrated on board of a military type unmanned aerial vehicle (UAV).

Although the commercial off the shelf network solution itself is broadly deployed, little is known so far how to operate and manage an airborne surveillance network node. The author shows that the use of unmanned aerial vehicles for networking purposes is not only possible but also manageable, even with remote operation of the unmanned aerial vehicle. The documented experiments over three generations of prototypes give insight about possibilities of how network infrastructure independence for the purpose of surveillance can be reached.

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AIRBORNE UBIQUITOUS SURVEILLANCE AND MONITORING NETWORK

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This thesis research examines the emergence of wireless technology as a pragmatic baseline supporting the goals of the Department of Defense in the development of Network Centric Forces. Increased international attention to the field of surveillance has developed in conjunction with the desire to interconnect all possible friendly forces in military operations and the Global War on Terror (GWOT).

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I. INTRODUCTION

A. BACKGROUND

By ‘intelligence’ we mean every sort of information about the enemy and his country – the basis, in short, of our plans and operations.

- Karl von Clausewitz: On War, 1832

At the outset, it is important to understand the distinction between information and intelligence. Information is an assimilation of data that has been gathered, but not fully correlated, analyzed, or interpreted. While not fully analyzed or correlated, information still has significant value to the tactical commander and plays a key role in threat warning and target acquisition.[1]

The collection, processing and transmission of information is the core of this research. The key role of surveillance is also identified in the area of humanitarian operations, where today fewer technologies, procedures and management processes are clearly identified or researched than in the battlefield segment. In particular, “big picture” surveillance, using unmanned aerial vehicles (UAV) with video cameras on board, is not known to have been previously used as part of the aforementioned operations. Roger Wedge, Aid for Aid fund raiser said, "There is a tremendous potential for UAVs to provide much-needed real-time imagery and communications links to support disaster-relief operations.”

Internationally, the United States will seek to screen and verify the security of goods and identities of people before they can harm the international transportation system and well before they reach the nation’s shores and land borders[2]. In that context, ubiquitous surveillance is one of the major foci of the Department of Homeland Security. The terminology of “ubiquitous” is described as omnipresent, present everywhere at once or seeming to be so. In an ideal

[1] Naval Doctrine Publication 2, September 1994

[2] Verrick French, Managing Director & Rebecca Dornbusch, Deputy Director, IBIA September 6, 2002; Available Online 01/14/2004, [http://www.technologyreports.net/securefrontiers/?articleID=546]

future scenario technology will allow the monitoring—on a 24/7 basis—of any area of interest from anywhere in the world. To accomplish these goals one must consider the underlying principles as well as the limitations of the used technology.

This thesis will elaborate on the previously completed work of Mike Ford and Leroy Dennis, “The Wireless Ubiquitous Surveillance Test Bed” (2003), as well as use and complete the hardware in place. Focus will be on integration of video sensors and the possibilities provided by a small UAV. The integration will mainly rely on commercial off-the-shelf products (COTS) and will specifically integrate a video camera and 802.11b networking technology. The necessary network reach-back will exploit the UAV as the network carrying node. Finally the tools for monitoring the network will be implemented in a situational awareness screen, which is the end of the chain that supports the decision maker.

B. PURPOSE

This thesis seeks possibilities for improving the integration of existing sensors and acquiring new components. Furthermore, the development of the surveillance network will prove the concept of using a UAV as a network node. A side product is the mobile network center, which allows the monitoring and maintenance of network operations. Finally, the situational awareness for the decision maker is the end product of the engineered system.

C. RESEARCH TASKS

Development goals for the thesis are:

- Set up a video sensor test bed similar to the one described by Dennis and Ford[3], which fused video sensing with biometric applications in order to prove the hypothesis for ubiquitous surveillance. The lack of a long-range ubiquitous network (most possibly wireless) is one of the identified needs.
- Setup a long-range network for transmission of the acquired data.

[3] Dennis, LeRoy and Ford, Micheal, Naval Postgraduate School (NPS), “Ubiquitous Surveillance” 2003, Available Online 01/14/2004, [http://library.nps.navy.mil/uhtbin/cgisirsi/Wed+Jan+14+15:09:36+PST+2004/0/520/03Mar_Dennis.pdf]

- Bring a wireless network node airborne for maximum range and flexibility.
- Integrate network management and situational awareness.

D. SCOPE OF THESIS

The scope of this thesis is to give a broad view on the subject and therefore may not delve too deeply into specific technical issues or configuration options. Nevertheless, the research goals will be accomplished and the proposed concepts proven.

E. METHODOLOGY AND ORGANIZATION OF STUDY

- Exploration and testing of network, sensors, network operations and management and situational awareness.
- Prototyping a small-scale-version surveillance network with airborne network node, integrated network monitoring and situational awareness as Decision Support System.
- Field testing of the prototypes in the Surveillance and Target Acquisition Network (STAN) experiments at Camp Roberts. STAN provides the resources and assets for academic level experimentation with military background. The purpose is to develop and field evaluate COTS-based systems which will provide the operator with an organic common operational picture[4].
- Assessment of operational requirements and accomplishments.

The iteration through multiple generations of prototypes will be shown as a successful approach for the systems development process.

[4] Christopher Manual, Naval Postgraduate School Monterey, 2004

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II. UBIQUITOUS SURVEILLANCE

A. DEFINITION OF UBIQUITOUS SURVEILLANCE

One of the oldest ways of detecting criminal activity is through surveillance. This method is used when it is likely that a crime will take place at a specific location or when certain persons are suspected of criminal activity. Certain circumstances may require mobile observation, for example aerial observation (using unmanned aerial vehicles (UAV)) or electronic procedures such as listening devices that monitor conversations or record video.[5]

From the Information Systems Technology stand point, the border lines of surveillance are determined by the possibilities that are technically achievable, ethically and affordably, considering the purpose. With that in mind, one might simply add the "Ubiquitous" to the "Surveillance", where a system is defined as a ubiquitous habitat when it meets the following characteristics:

- "pervasive—it must be everywhere, with every portal reaching into the same information base
- embedded—it must live in our world, sensing and affecting it
- nomadic—it must allow users and computations to move around freely, according to their needs
- adaptable—it must provide flexibility and spontaneity, in response to changes in user requirements and operating conditions
- powerful, yet efficient—it must free itself from constraints imposed by bounded hardware resources, addressing instead system constraints imposed by user demands and available power or communication bandwidth
- intentional—it must enable people to name services and software objects by intent, for example, "the nearest printer," as opposed to by address
- eternal—it must never shut down or reboot; components may come and go in response to demand, errors, and upgrades"[6]

5 Microsoft® Encarta® Reference Library 2003. © 1993-2002 Microsoft Corporation.

6 Johnson, R. Collin, Advanced Technology, "Companies Test Prototype Wireless-Sensor Nets", January 29, 2003, Available Online, [http://www.eet.com/at/news/OEG20030128S0028].

B. IDEA, COMPONENTS, AND ARCHITECTURE

1. Idea

Since some of the more specific objectives of surveillance are the enhancement of Special Operations Forces (SOF) ability to find, fix, and identify enemy personnel and equipment while reducing blue-on-blue incidents, they perfectly match what this research proposes to deliver. The following ideas stand behind the development of the airborne surveillance test bed:

- Support the decision-making process.
- Allow remote access to data without endangering the warfighter.
- Enhance covered network range and allow flexible remote sensing.
- Reduce bandwidth requirements.

2. Components

In order to enhance overall operational and tactical awareness in a large area, several factors regarding the used components need to be considered:

The size of the area mandates the establishment of a huge network. Here the network coverage will be accomplished by a UAV (or other air vehicles such as a balloon) acting as a mobile network node for the 802.xx wireless networking standards.

The network needs monitoring to determine availability, reliability and quality. This requires the establishment of a mobile network operations center.

In order to keep utilized bandwidth at a minimum, clustering of sensors in proximity to one another is used. Clustering here means deploying a platform locally networked with the sensors. This allows auto alert features and media streams on demand at a minimum use of bandwidth.

All parts of the test bed and its integration are COTS. This facilitates the usually long-term logistics of any federal or governmental operation. This also meets the latest requirements of network centric warfare, not only of the United States Department of Defense but of other agencies as well.

As a conclusive requirement for the network node and the sensors, certain environmental parameters, low physical weight and dimensions as well as low power consumption and grid independence need to be fulfilled.

3. Architecture

The following diagram shows a remote site connected to an operations center via the envisioned unmanned airborne network node. This will allow flexible, very covert operation and extended ranges into unknown or hostile territory. Employing existing 802.11b standard wireless network technology will allow the integration of unattended or airborne unmanned sensors and/or manned aircraft with ease. Global Positioning Systems will make geo locations of all devices available at all times for all participants and integrate seamlessly into situational awareness and targeting. Decision support can be leveraged to any scale by connecting in to existing C2 systems.

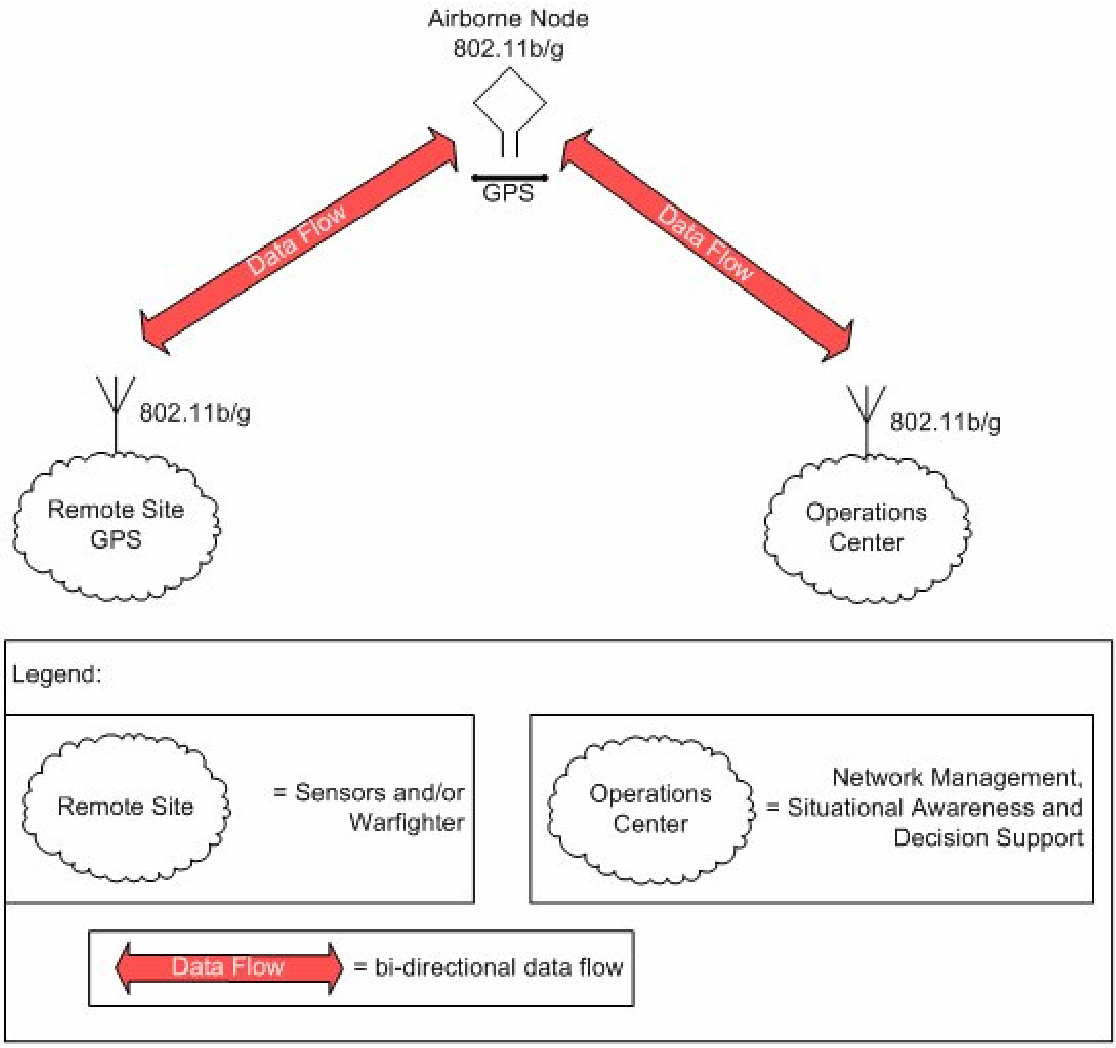

Figure 1. Building Blocks of the Ubiquitous Surveillance Network

C. SUMMARY

Focusing on the airborne network, the development will occur in a spiral model over a number of prototype evolutions. One foreseen difficulty is the complexity of all the interdependencies introduced with the unmanned aircraft. Limited availability and time constraints will certainly influence testing and development. Breaking the development down into lab exploration, ground-based testing for short and long ranges, and finally airborne trials is the preferred methodology. It not only avoids useless effort due to almost impossible remote adjustments while airborne, it also allows the evaluation of different types of equipment and software.

Rugged and sophisticated components are needed for use in a UAV. Accepting this “must” from the beginning leads to the recommendation to use only consumer-grade equipment in the tough environment of airborne vehicles. The possibilities for sensors are vast, allowing the system to be tailored to its exact purpose. Greater variety in sensors means achieving more objectives, which translates into a more useful surveillance network. At a glance, we know from today’s C2 systems that the usefulness is constrained by the network limitations such as range and throughput.

The goal is to balance between the ultimate system’s solution and the constraints and limitations of which the most important are listed as follows:

- Mobile versus static sensors including power independency and ease of deployment.
- Airborne COTS video sensor, implying low weight and low power requirements, along with high resolution, pan-tilt and zoom functionality. Also, the threshold operating environment needs to be considered.
- Limited available network bandwidth.
- Long-range networking for mission-critical applications.
- Limitations of situational awareness in displaying sensed data and acting as a decision support system.

The COTS market offers a huge variety of sensors, networks and related applications. The difficulty is to find the right combination that leads to a useful, deployable and helpful system, which supports the decision maker in his or her original task – making the right decision on the basis of the right data. This can only be accomplished by developing a system considering the limitations as shown above. The most important part appears to be the integration and transformation of the whole array of sub-systems and components into a system that meets the objectives.

Believing that the concept is valid and worthy of exploitation and proof, the following chapter will describe the development of the subsystems for video sensing, networking and network management. This development will lead to a working prototype, which will be presented in order to examine deviations of theory from practice as well as the need for additional functionality and concepts.

III. SYSTEM COMPONENTS

The components considered in the development of the test-bed are chained as follows: Sensors – Network – Network Ops Center.

The functionality of each component is determined by the following simplified description: sensors detect events; the network itself transmits the alert and/or data if requested, and finally the Network Operations Center (NOC) receives alerts and data while monitoring and managing the network status. The operations center facility might be a big installation in a fixed location, providing situational awareness, decision support and network management, or it may be a mobile Command Post (CP) which provides basic network monitoring and decision support in reduced form. An additional functionality found to be useful is the Airborne Node Monitor, which needs to be part of the NOC or CP employing UAVs. The newness of managing an airborne network node allowed the author to develop a method to tailor UAV flight operations to the needs of networking. Chapter V indicates keys in network operations and will introduce a solution for airborne networking node awareness.

The immediately following chapters follow the functional chain sensor – network and will show in depth an evolutionary development process for the airborne networking node in the part “Operational Systems and Evolutions”.

A. SENSORS

The chosen approach for sensor evaluation and integration changed over time due to the fact that the UAV networking was more resource intense than initially planned. Therefore, the sensor work area was reduced to one of the most important sensors today, the video sensor. A video sensor or camera is of primary importance for various reasons. First, today’s COTS market delivers an uncountable number of cameras for almost any application. The hardest part is once again to identify the product that fits the purpose, which leads back to an old systems-development problem that still awaits a solution: try as we might, there is no way to determine how all objectives can be fulfilled upfront. This leads

to an incomplete requirements listing which itself will adversely affect the specifications in the systems engineering phase.

Recognizing this lack, in combination with time and resource constraints, this thesis work focused on identifying one suitable video sensor, which could be used as an unattended ground sensor system. Since the surveillance is supposed to be ubiquitous, possibly pervasive, independent and as intelligent as possible, attributes like size and weight, power consumption and environmental specifications were considered during development: Also, automatic, standardized, and possibly wireless networking functions were desirable in order to facilitate networking, network management and deployment.

1. Video Cameras

The following COTS models were evaluated and physically integrated into the test bed:

No	Manufacturer	Model	Extras	Connection	Picture
1	CANON Industry Standard	VC-C4	Pan-tilt	S-Video/ Composite RS232	
2	VEO Web Cam	Mobile Connect	N/A	USB 2.0	
3	LOGITECH Advanced Web Cam	Quick Cam Orbit	Pan-tilt Auto Face tracking	USB 2.0	
4	Dazzle Video Converter	80		S-Video / Composite to USB	

Table 1. Video Camera Models and Specifications

The Canon model VC-C4 is the most sophisticated camera with the best specifications among the compared models. Due to the analog video signal output, an additional video converter is needed to digitize the signal. This was achieved by using the Dazzle Digital Video Creator (Number 4 in the table) which connects via USB to any PC running Windows. The pan and tilt controlling application is also available as a Software Development Kit for further integration and adaptation.

The quality of the cameras is directly proportional to the pricing which ranges from $1000 (Canon), $130 (Logitech) and to $69 (VEO). The Logitech

and VEO cameras come with vendor specific software and drivers and are comparable in picture quality and speed (frames per second).

The Canon model is the only model delivered with a customizable user interface for the pan-tilt functionalities which includes presets for predefined camera angles and zoom-adjustments. The available SDK allows further integration and adjustment to special needs. The test-bed evaluation of all four cameras quickly made clear that only the Canon VC-4 is appropriate for use when a high-quality motion picture is needed. The result was reached by evaluating the criteria of speed (frames per second delivered) and resolution. Aside from that, size, zoom and pan-tilt capabilities as well as light sensitivity and auto focus play an important role. As in all other areas it became quickly apparent that only industry standard and above can fulfill the requirements.

Summarizing the specifications for the CANON VC-C4 camera will lead to the connection between the camera and the network. Questions answered in the next section are: How to integrate the sensor into the network? How to keep the sensor unattended? How can bandwidth be throttled?

Canon VC-C4 specifications at a glance:

VC-C4 Camera	
Total Pixels:	470,000 (440,000 effective)
Zoom:	16x
Focus distance:	4 to 64mm
F-number:	f/1.4 to 2.8
View angle:	47.5°
Iris control:	Auto iris servo system
Horizontal resolution:	420 TV lines
Vertical resolution:	350 TV lines
Pan range:	+ or - 100°
Pan speed:	1 to 90°/s
Tilt range:	-30° to +90°
Tilt speed:	1 to 70°/s
Power consumption:	12 Watts
Video Outputs:	RCA and S-Video
Control terminals:	RS-232C, 8 pin mini DIN, in and out
Dimensions (WxHxD):	100 x 89.5 x 112 mm
Weight:	440g

Table 2. Canon VC4-C4 Specifications

2. Network Connection

Bandwidth is usually the most valuable asset in the scenario of surveillance. The link back to a Network Operations Center is usually the weakest element in the chain down to the evaluating decision maker. In order to use the available bandwidth at a minimum and only when necessary, any transmission of data needs to be restricted to an absolute minimum. This requirement leads to the idea of sensing an occurrence, processing it, creating an alert and sending this alert across the network. Since the amount of data that an alert consists of is very small, the network is utilized at a minimum, which is a maximum of positive accomplishment. Once an alert reaches the Operations Center, the decision maker can initiate a video on-demand procedure with the purpose of further investigation.

In the context of minimizing data flow across the network, useless data flow can be considered--for example a video stream that is not analyzed or watched by a person for evaluation. In order to preprocess the huge amount of video sensor data before it enters the network, a local platform with adequate processing power is needed.

In order to convert the analog video stream of a camera into an alert that requires almost no bandwidth, the sensed occurrence must be processed on site. This implies that the sensor needs onboard processing power and networking capabilities.

Two approaches can be pursued. The first one processes the video signal with an attached laptop and transmits the alert. On demand, the video stream can be acquired remotely. For that purpose, the market was researched for a simple software solution. The chosen product features motion detection, masking of the camera view, and various alerts as well as storing, uploading, and execution options. The motion detection feature can be used to execute a software agent that issues the alert to a remote server. There it is displayed on a situational awareness screen, which places icons over a map on the geographical locations of the remote platform and the camera. An incoming alert

causes the icon to blink. The icon can be clicked for detailed information. Also, the pan-tilt controls for the CANON VC-C4 camera become available as soon as the video transmission is activated. Figure 2 depicts the architecture that is able to determine connectivity, network utilization, and link quality. These controls allow the adjustment of network utilization and bandwidth.

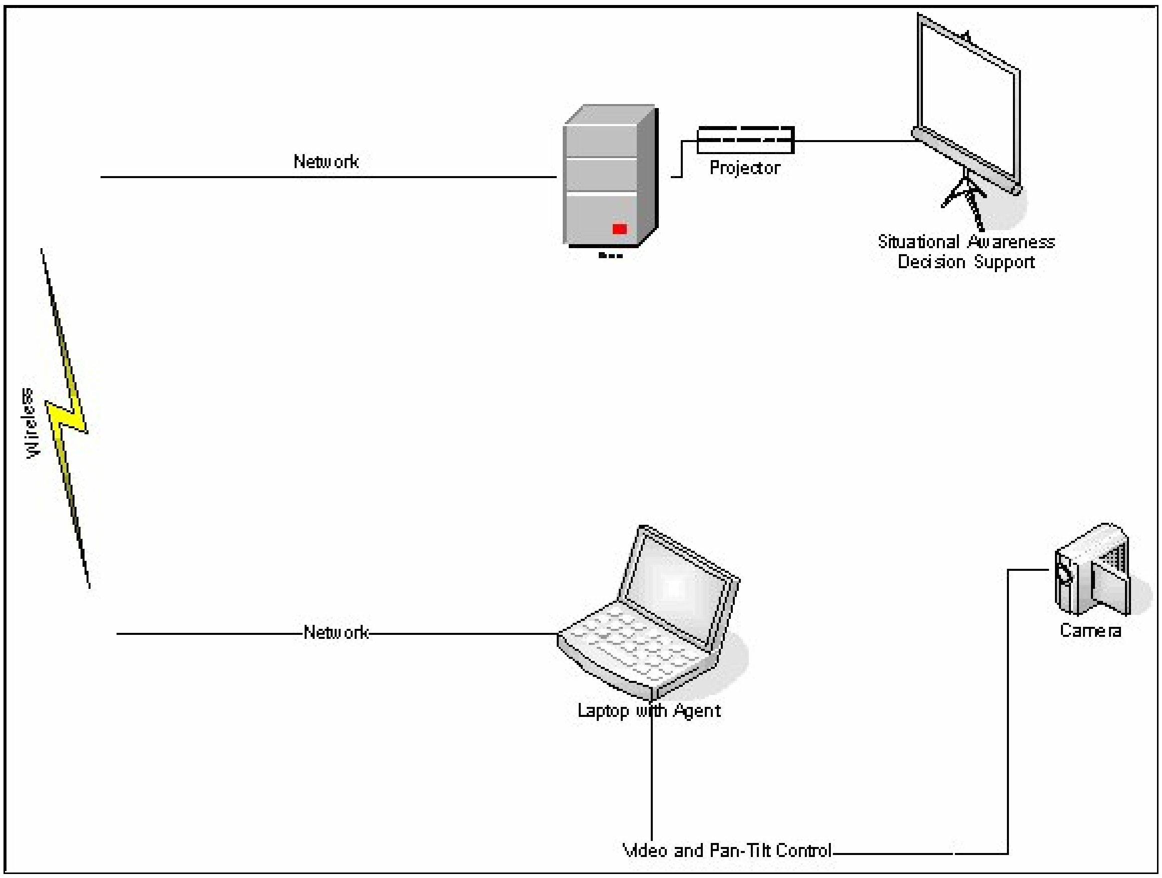

Figure 2. Architectural Overview of the Situational Awareness

Another approach would be to use a camera that has the processing power integrated and features motion detection and web service. For evaluation, the test bed was extended with two web cams that have broadcast (web service) functionality. The missing motion detection could be realized in the remote network center. The Panasonic KX-HCM230 outdoor surveillance camera was found to be suitable for its rugged design and the built-in web server as well as pan-tilt functionality.

Key Features Panasonic KX-HCM230	
Interface Type	LAN
Digital Video Capture Speed	15 frames per second
Compatability	Windows
Still Image Capture Resolution	640 x 480, 320 x 240, 160 x 120
Video Capture Resolution	160 x 120, 320 x 240, 640 x 480

Table 3. Key Features Panasonic KX-HCM230

Figure 3. Panasonic KX-HCM230

Although easy to operate, any web camera will clog the network due to the fact that it is always broadcasting. Once a certain threshold is reached, which is simply limited by the onboard processing power, this maximum broadcast of data is maintained as long as the network allows it. Having perfect network conditions, a continuous network utilization of approximately 1 Mbps was reached. This is very undesirable and not necessary for a fragile long-range wireless airborne network. Also, the minimal buffer capability on board is not suitable to handle a disconnect from the core network for the reason that all data is lost during disconnection.

In conclusion, today's assortment of web cams is not suitable for the planned purpose. The video sensor of choice should always be capable of processing the video stream to an alert with the option of transmitting high-

resolution video on demand only. A buffer at the remote site allows rewinding and conserving of data during times of disconnection. The following pictures show the actual engineered system following the depicted architecture of Figure 2. A screenshot of the situational awareness screen is shown in Figure 5.

Figure 4. Remote Sensing Station with Pan-Tilt Camera

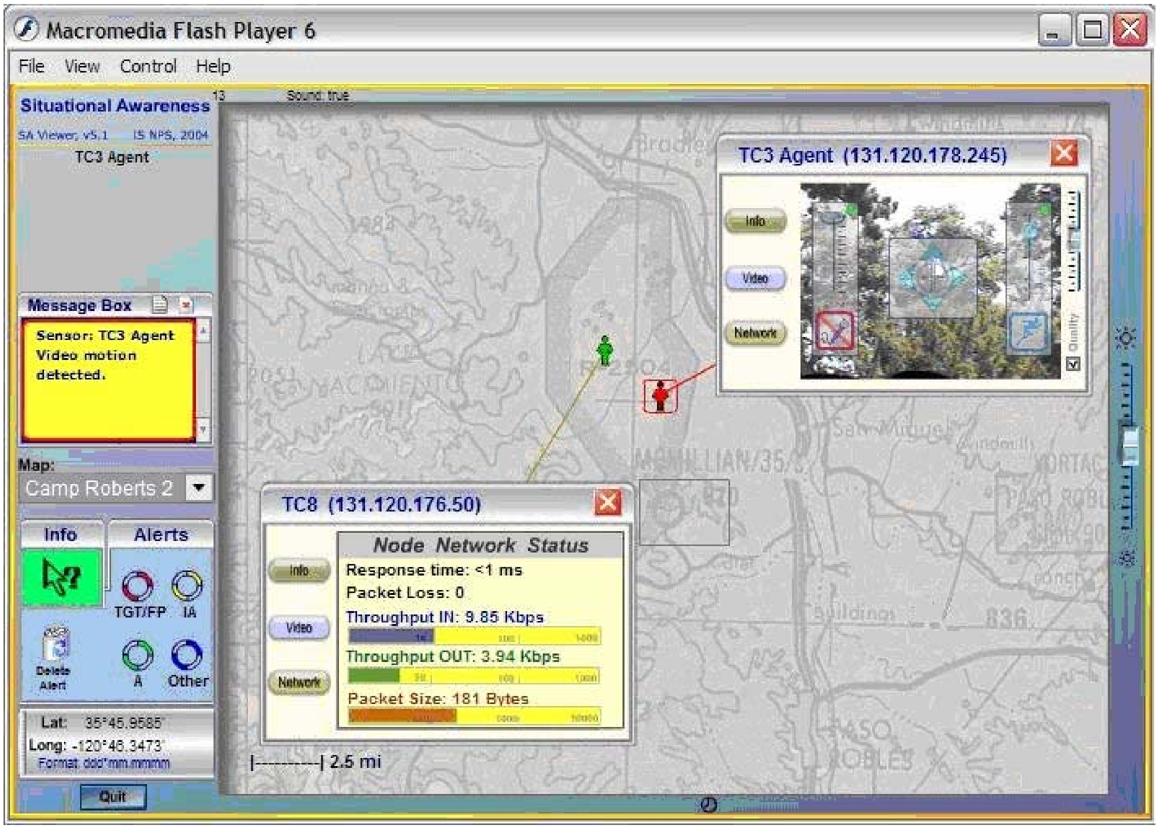

Figure 5. Situational Awareness with Network Status and Video Stream

Note the transparently visible camera controls in the video window. Network awareness is accomplished by displaying the SNMP service data of the node.

3. Summary

Evaluating the possibilities of video sensor integration is important with regard to two factors: first, to create a useful surveillance application for the decision maker and second, to continue to adjust the currently useful, but heavy load for the planned prototype network. Section B reviews the topology, components, and the used type of UAV on the wireless networking side, which is the core part of this research.

B. AIRBORNE NETWORK NODE

1. Network Components

The networking component was approached in the IEEE 802.11b domain. In order to have a robust start and due to commitments to sponsor requirements,

the CISCO AIRONET 350 bridges were primarily evaluated and employed. This chapter breaks down the functional chain into the following sub-components of a wireless network:

- Bridge Radio (ref. CISCO here)
- Amplifier, appliances
- Antenna

Each area has its specific problems and configuration issues, but the main area of problems was identified with antennas. There is a whole own-research area existent that works on antenna design and optimization. Here, the author’s experience and the extensive field testing were found to be suitable to find the optimal solution. From the engineering perspective, main effort was put into the need to package a network node and have it operational in an UAV. Long-range performance, weight and power consumption were factors that are usually not considered in a consumer grade network deployment. They find consideration in the chapter NETWORK. The used unmanned aircraft is described in the same chapter in the section UAV.

2. Topology

Due to the fact that the CISCO AIRONET 350 bridges were available for experimentation, the long-range networking was strictly developed in infrastructure mode. Intensive lab and field testing with the CISCO bridges showed that the best choice for the Root Bridge is the mobile, airborne node. The terminology evolves from the CISCO notation, where network components are defined by their roles as follows:

Root Bridge: One bridge in each group of bridges must be set as the root bridge. A root bridge can only communicate with non-root bridges and other client devices and cannot associate with another root bridge.

Non-Root Bridge w/Clients: Use this setting for non-root bridges that will accept associations from client devices, and for bridges acting as repeaters.

Non-root bridges can communicate with other non-root bridges, root bridges, and client devices. Figure 6 shows a root bridge communicating with non-root bridges.

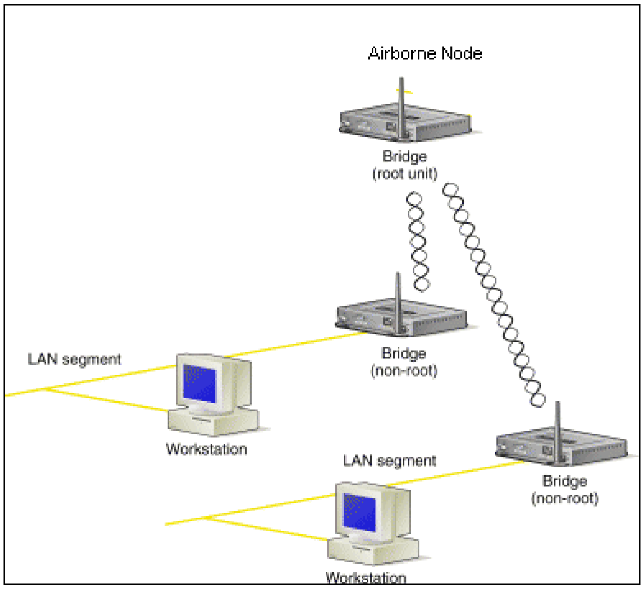

Figure 6. CISCO notation for roles in wireless networks

There are various attributes to be considered when choosing the components for a network in tough environmental conditions. The airborne node in particular has restrictions on power draw, weight, and physical dimensions.

The antennas and their radiation patterns were found to be the most difficult part to determine and choose. It will be shown how these considerations evolved over the evolution of the airborne network component, later referred to as payload.

Following the outlined methodology, the development was staged in generations, where each generation went from the initial idea through a lab setup and a final field test. Lab tests were limited to FCC regulations and constrained by real estate limitations that did not allow for proper testing of ranges. This proved the field tests, which were integrated into the “Surveillance and Target Acquisition Network” (STAN) at Camp Roberts, to be very useful.

3. Airborne Vehicles

a. Tactically Expendable Remote Navigator (TERN)

The BAI Aerosystems TERN is a compact, tactical UAV capable of performing a variety of remote sensing, precision dispensing and other aerial robotic missions. TERN is constructed of composite materials and features a high wing design and increased ground clearance, which allows operation from runways and semi-improved surfaces. A 100cc two-stroke, gasoline/oil engine powers the TERN.

TERN employs a global positioning system (GPS) autopilot that controls vehicle heading, altitude, airspeed, and GPS waypoint navigation. A 10-watt video/telemetry microwave datalink transmits real-time imagery and vehicle telemetry back from the aircraft at ranges up to 50km. For STAN6, TERN was equipped with an 802.11b bridge, a 2W amplifier and an omni-directional antenna, mounted in the nose. Figures 7 and 8 provide illustrations of TERN operations. Table 4 provides TERN's specifications.

Figure 7. Balanced TERN with Network Payload in Nose

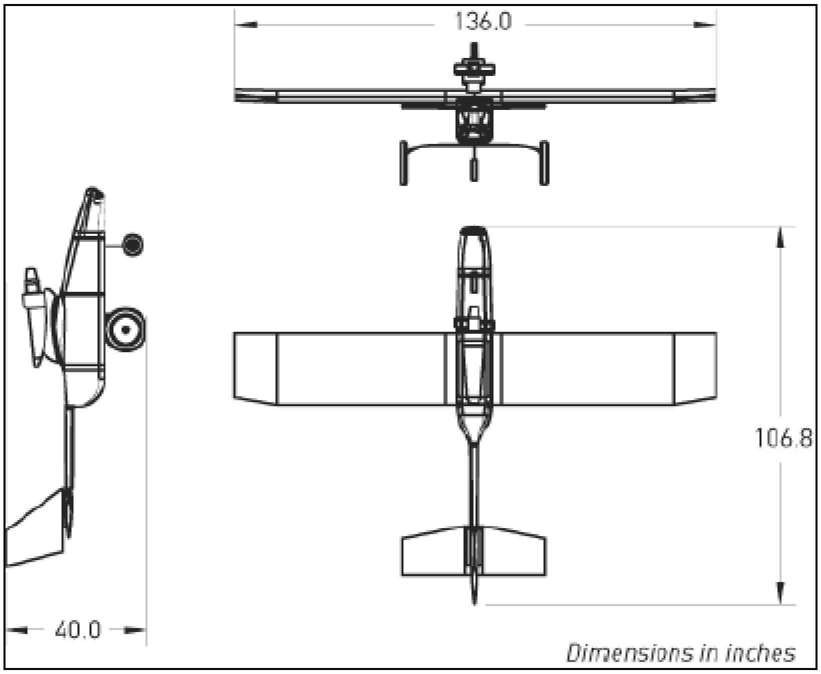

Figure 8. TERN Dimensions

TERN Specifications	
Stall Speed	45 mph
Max Speed	78 mph
Cruise Speed	52 mph
Operational range (still air)	200 miles
Operational Endurance	4 hours
Ceiling	5000 - 6000 ft.
MGTOW	130 lbs.
Empty Weight	95 lbs.
Maximum Fuel	28 lbs.

Table 4. TERN Specifications

For STAN6, Navy Composite Squadron SIX (VC-6) used the TERN Ground Control Station (GCS) shown in Figure 9. The GCS features a microwave receiver, amplified uplink transmitter and a rugged laptop computer with flight control software. The TERN's typical payload is an infrared (IR) or electro-optical (EO) sensor. For STAN6, the payload was the Generation2 NPS Network package.

Figure 9. TERN GCS

b. Balloon

As a backup and surrogate to the TERN, a 13-ft. diameter balloon capable of 60-lbs of lift was used for initial connectivity and link quality checks. The balloon is an excellent network relay node to test the network. The balloon's payload consists of an 802.11b Cisco bridge with a 5W amplifier and a 6dB gain omni-directional antenna. It also includes a 12-channel GPS Receiver and a 900MHz Freewave transmitter for the GPS broadcast. The payload was powered by two 5390 Li-MnO2 Batteries. The balloon and its payload are shown in Figure 10.

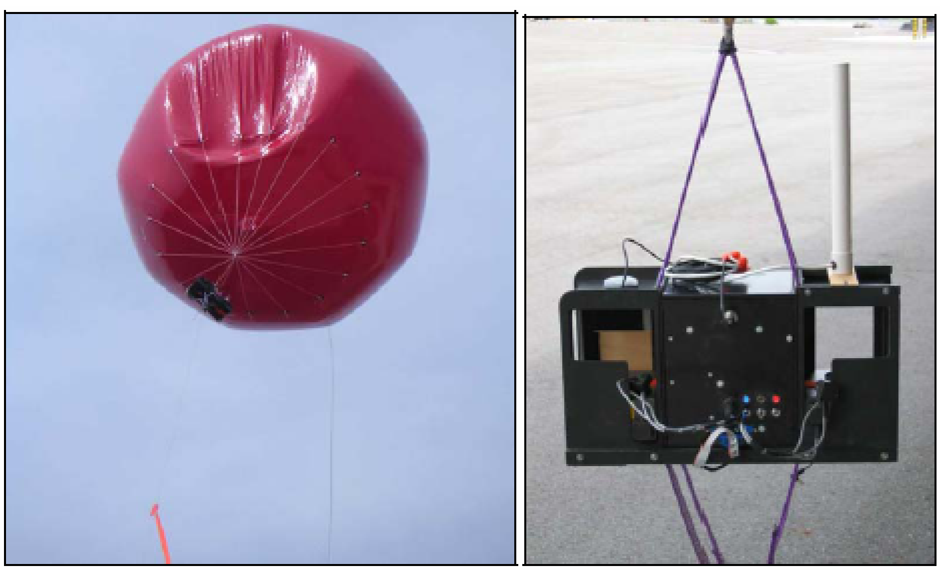

Figure 10. Balloon and Payload

4. Payload Specifications

Describing the technical specifications of all components in detail is not intended here. The following is an overview to gain a quick oversight and an excerpt of the evolution of the prototypes.

a. Transmitting Power

The CISCO AIRONET 350 bridge being connected to an amplifier which itself is connected to an antenna resembles the functional chain on the radio side. The bridge was used with all generations while the amplifier changed from initially 1 Watt to 2 Watt in Generations 2 and 3. A variety of antennas were tested, considering radiation pattern and gain. The major limitation regarding the antenna on the UAV is the fact that the antenna needs to work without a ground plane. The omni-directional antenna mounted ventrally in figure 7 (generation 2) was found to provide the best range and independence of aircraft attitude, while maintaining a radio link of good quality. Details on the experiments with each generation can be found in the respective sub chapters of IV. “Operational Systems and Evolutions”.

b. Power Consumption

The required power was determined by measuring the voltage under load from system boot-up to the point of smooth operation (~3min.). Minimum and maximum values for current were recorded and an average power draw was calculated by interpolating the min and max values for wattage.

Generation 1: average P = 12 Watt

Generation 2: average P = 15 Watt

Generation 3: average P = 20 Watt

c. Endurance

Subsequently the endurance was determined by referring to the battery type and it's specifications below.

Battery: Ultralife Batteries, Inc Type: BA-5390/U


[7]

Generation 1:	22 hours
Generation 2:	21 hours
Generation 3:	13 hours

Compared to the endurance of the UAV itself (max 4 hours), the battery life is relatively high. This is an excellent opportunity for the follow-on lightweight version to employ a much lighter and smaller battery.

d. Weight and Form Factor

Weight had to follow functionality and therefore was not optimized in this development. As this paper is published, the follow-on work by Dr. Kevin Jones, Naval Postgraduate School, carefully considers weight and form factor. Generation 4 will be down to ~1000g while maintaining the functionality of generation 3. A picture of the preliminary design can be viewed in section D, Outlook and Recommendation.

Generation 1:	2600 grams
Generation 2:	2730 grams
Generation 3:	2900 grams
Generation 4:	1000 grams

e. Picture Gallery

[7] Available Online www.ultrabatteries.com 08/30/2004

Figure 11. Generation 1 Payload

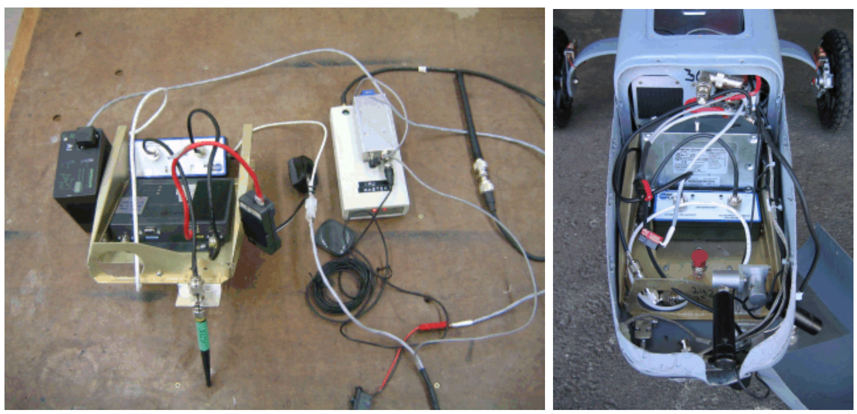

Figure 12. Generation 2 Payload

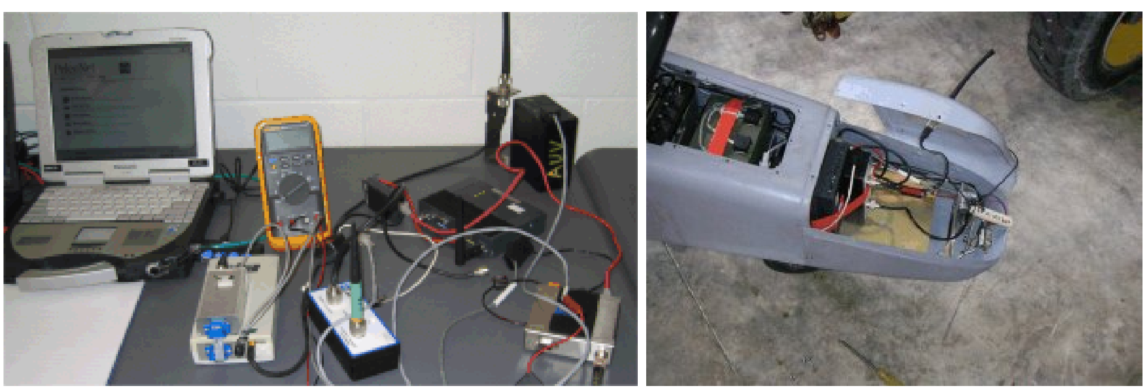

Figure 13. Generation 3 Payload

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IV. OPERATIONAL SYSTEMS AND EVOLUTIONS

A. GENERATION 1 (STAN 5+)

Generation 1 (G1) was the initial test where the basics were learned to handle the CISCO 350 bridges. This painful lesson was learned in preparation and execution of the STAN 5 experiment. It was also found that an experiment definitely needs laboratory testing before going out to the field.

1. Functional Description

The following functional components are needed to establish a basic wireless network:

(Root) Access Point – bridges between LAN and Radio-Link, acts as repeater and access point. In the following referred to as “Bridge”.

Amplifier – amplifies the radio signal

Antenna – radiates the amplified signal into the atmosphere

In addition one needs a power source, various DC voltage converters (DC – DC), switches for cycling the power as well as a suitable wiring harness.

2. Architecture

The architecture for Generation 1 is laid out in Figure 14. Note the omni-directional connection between all nodes.

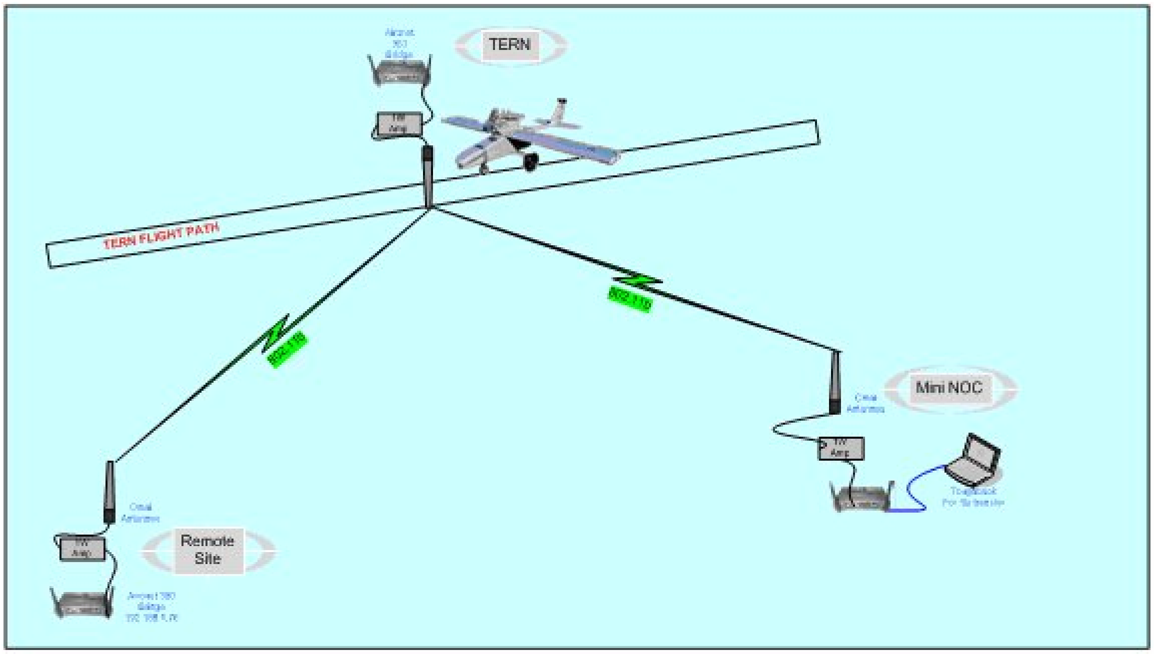

Figure 14. Generation 1 Architecture

3. Components

Bridge. Since the CISCO bridges (Figure 15) are ruggedized devices for industrial use they were found to be suitable to be used in a rough environment, field tests and onboard unmanned vehicles.

Figure 15. Ruggedized CISCO 350 AIRONET Bridge

Amplifier. The chosen amplifier is a 1 Watt LUXOL amplifier with a working frequency range of 2.4 to 2.5 GHz. The relative wide frequency range

allows for the adjustment of the used channel in the 802.11b domain with no restriction. This proved to be helpful for later deconfliction with other networks.

Antenna. In order to achieve maximum field strength surrounding the airborne node, a unity gain (0dBi) dipole antenna was initially chosen. The rugged design of the antenna and the small form factor allowed testing of various mounting positions and orientations. At that point this was the only antenna available that did not require a ground plane. Another reason to favor the unity gain antenna was its perfectly circular radiation pattern, which promised total independence of aircraft attitude (e.g. banking).

Reasoning for antenna choice:

The gain of the antenna affects the way the signal is distributed. It is not possible to create more power from the transmitter by adding a higher gain antenna, however it is possible to send the signal to where it most counts. As long as the mobile antenna is not electronically or electromechanically controlled towards the emitter, it has to be omni directional, which means it radiates the signal 360 degrees around the antenna. The radiation pattern of the antenna describes how that signal is distributed in the 360' fashion. Figure 16 shows the side-on view of the radiation pattern of the signal from a unity gain antenna.

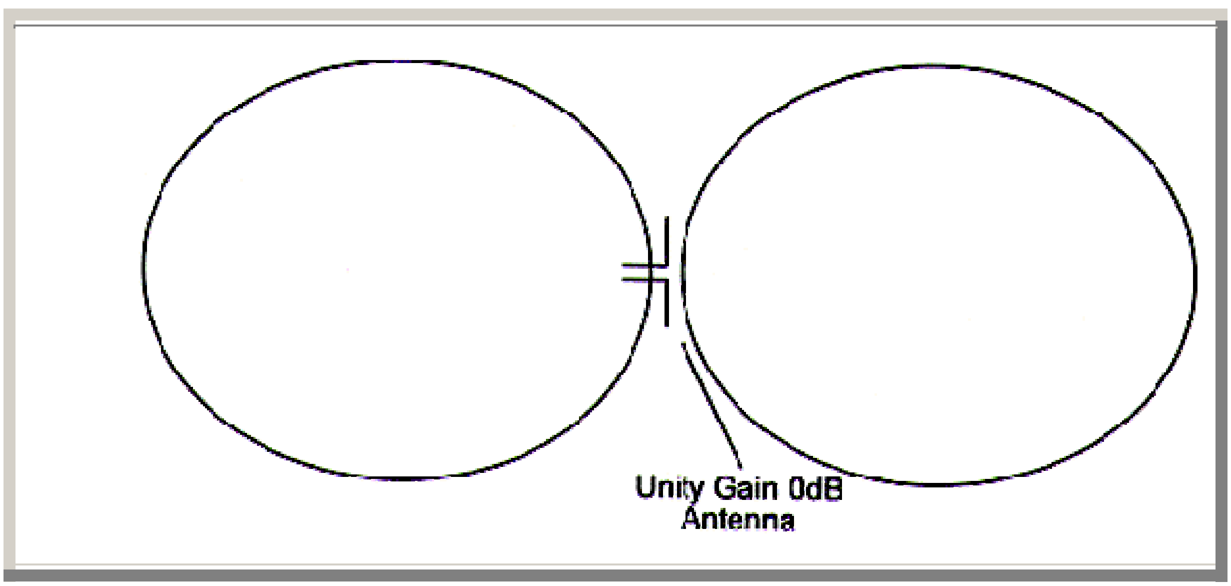

Figure 16. Unity Gain Antenna 0 dB

The two circles represent the side view of a large doughnut shaped radiation pattern. From this shape it can be seen that the signal is spread evenly upwards, downwards and sideward. This shape of radiation pattern suits an environment where many hills and dips are present and need to be covered. The signal is spread in all directions, meaning there is a better chance to reach a remote site from the bottom of a dip or from behind a building.

As the design of the antenna is modified and the gain increased, the doughnut-shaped radiation pattern is squashed flat. Figure 17 shows how the gain (the higher the more) flattens the omni directional radiation pattern and therefore increases the range.

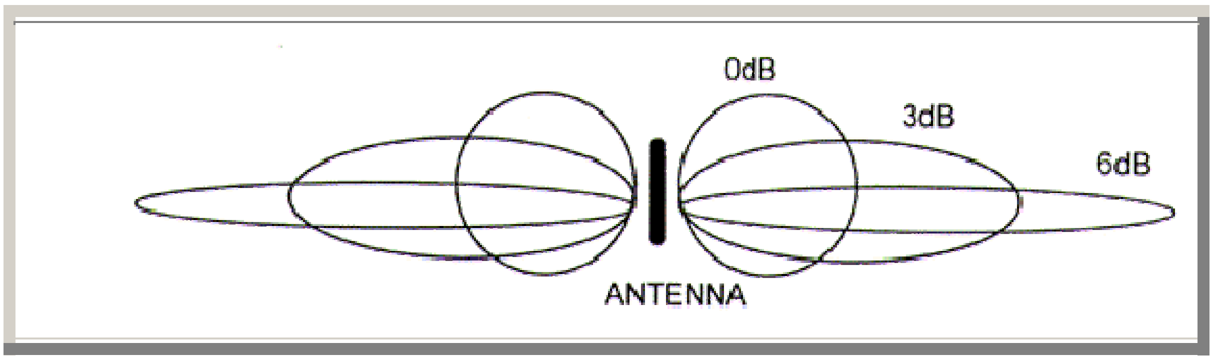

Figure 17. Radiation Pattern for 0, 3 and 6 dB

The above diagram compares a Unity gain or 0dB antenna with 3 and 6 dB radiation patterns. It shows clearly that it is possible to communicate with a remote site further away.[8]

Connectors and Cables. Typically on amplifiers and antennas, N-Type connectors are standard. The bridge itself has a reverse SMC antenna output connector. In order to minimize the loss of roughly 0.3 dB per connector, the goal must always be to minimize the number of adapters and the total length of the transmission line between bridge output and antenna. In order to reduce the weight, one might consider using the mc or mmcx connectors, shown in Figure 18.

[8] Benchoam, David BE (EE); Cellular Antennas, 2004

Figure 18. Various Antenna Connectors[9]

4. Test Description

The initial testing was conducted in the GigaLab for basic configuration and then in the proximity of the Naval Postgraduate School for range testing. For that purpose one bridge/amplifier/antenna set was installed on the roof of Spanagel Hall (25m height), while the mobile set was mounted in/on a vehicle. A handheld GPS device allowed the accurate determination of the distances and elevations. The following table shows the achieved ranges and data rates.

[9] Available Online http://www.wlanantennas.com/antenna_connectors.htm; 08/30/2004

Distance [m]	Elevation [m]	line of sight	link up	avg. latency w/o load [ms]	avg. latency w/ load [ms]	link quality [kbps]
3400	190	Yes	constantly	unknown	unknown	1000
3500	260	Yes	constantly	unknown	unknown	1000
3400	300	Yes	constantly	30	unknown	1000
4400	100	Yes	constantly	24	630	730
4300	30	Yes	constantly	35	559	300

Table 5. Distance, Elevation and Link Speed

The data is considered to be reproducible and useful; it clearly shows the degradation of the link quality over distance.

After installation of the payload onboard the NPS-owned UAV TERN, a test flight for connectivity and range determination was undertaken at Camp Roberts, CA.

Unfortunately, the experiment was limited to a single flight, which disallowed systematic data acquisition. Follow-on experiments, with the balloon as surrogate and equipped with identical payload, allowed for the determination of a maximum distance with good link conditions of 4.72km (altitude 550m). The link speed varied from 170 kbps up to 217 kbps.

The major finding during the experiment was that a higher-gain antenna would help to increase range without degrading the link quality due to the quickly changing attitude of the aircraft.

B. GENERATION 2 (STAN 6)

1. Evolution

Generation 1 proved the concept of an airborne network node to be useful and doable but achieved ranges were not satisfactory. The reason for that is clearly identified in the low gain of the omni-directional unity gain antenna in combination with the 1-watt amplification. With this in mind, and recognizing the opportunity to use a prototype antenna with high gain, amplification and tracking capability, the idea for Generation 2 (G2) unfolded as follows:

From G1 to G2, the overall architecture of the airborne node system was not changed. The significant change came with the implementation of the tracking antenna. This antenna, referred to as K2 (Figure 19), is a prototype, manufactured by Sierra Nevada Corporation. It not only acts physically as the receiving antenna, but also provides a variety of functions in addition to support the tracking process. The functional architecture of this system may be depicted as shown in Figure 20:

Figure 19. K2 system with Battery Pack and Laptop

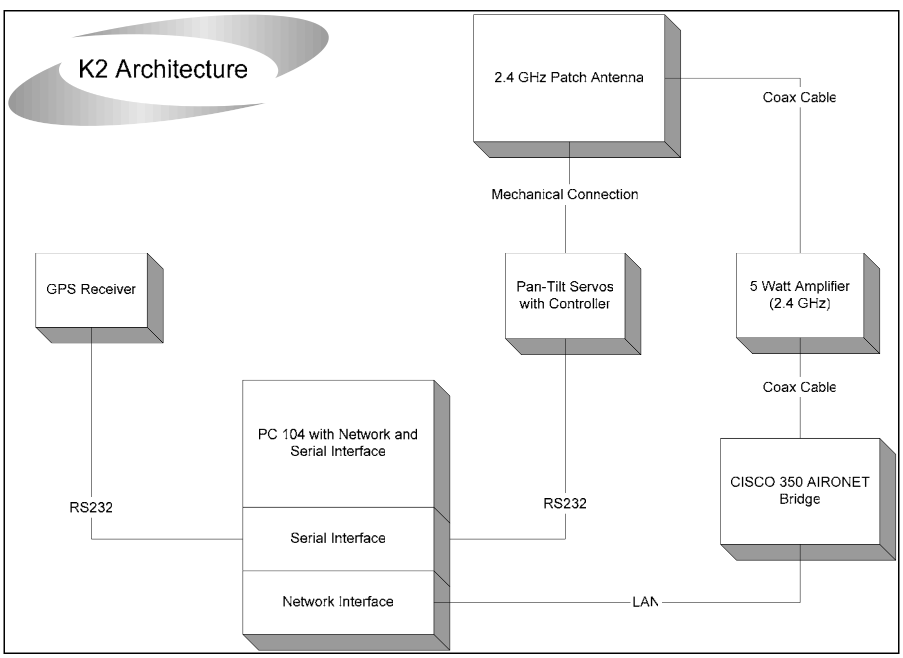

Figure 20. High Level Architecture of K2 Tracking Antenna

2. Functional Description

In order to have a reference to the UAV’s location, the location of the K2 is derived from the GPS data provided by the GPS Receiver. Together with the received location of the UAV via multicast message over the LAN, the processing unit (PC-104) can determine the control data for the Servo Controller. This pan-tilt servo controller then physically aligns the patch antenna towards the UAV in terms of correct bearing and azimuth. In combination with the 5-Watt amplifier between the bridge and the antenna, this setup allows long-range connections far beyond common ranges (and FCC regulations), since the patch antenna is radiating the highly amplified signal precisely in the direction of the UAV.

Obviously, the UAV should never lose the line-of-sight to the K2 antenna, since re-establishing the link is very difficult due to the fact that the UAV’s geo location is acquired via the 802.11b link. In case of 5 missing multicast messages (equivalent to 5 seconds), the antenna switches to a scanning mode that follows a certain search pattern in order to re-acquire the 802.11b signal from the UAV. In addition to this, another inherent disadvantage of this functionality is on the tactical side, where the UAVs takeoff location is covered and/or unknown. The K2 antenna system as it is currently engineered by Sierra Nevada Corporation does not allow fast and guaranteed signal acquisition. But most tactical scenarios do require the independence of the UAV’s 2.4 GHz signal acquisition.

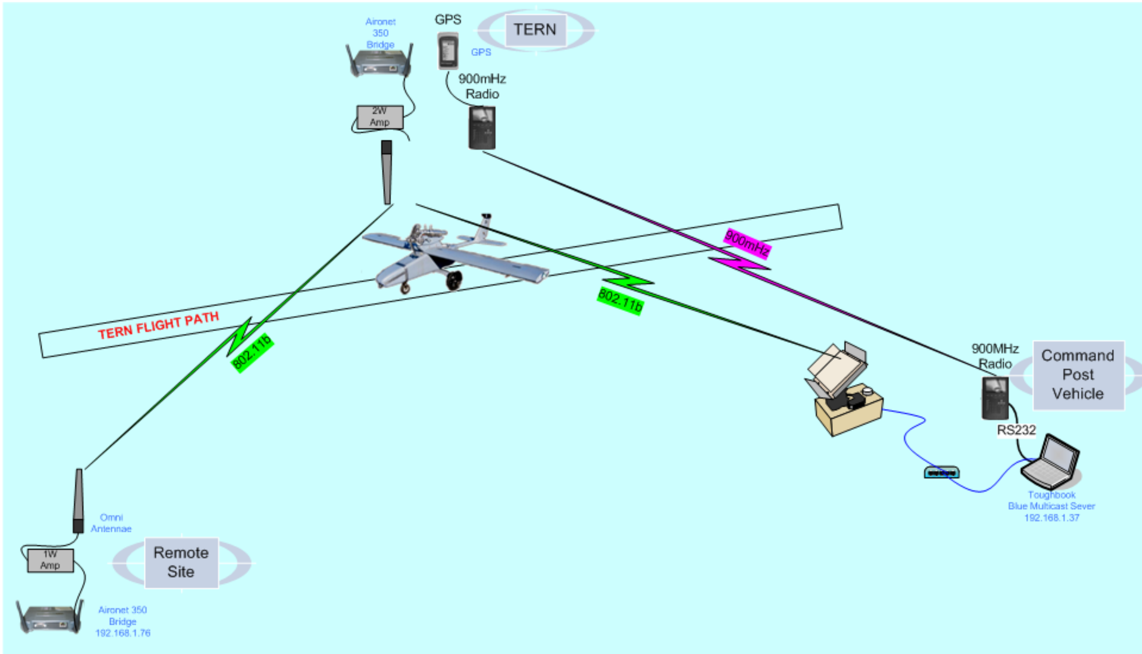

Figure 21. Architecture Overview for 2.4 GHz independence

This disadvantage was overcome by the implementation of the independence of the 802.11b link to acquire the geo location of the UAV. This was achieved by transmitting the onboard-derived GPS data via a separate 900MHz radio link. The remotely received GPS data was then made available by the same technique as before, using multicast messages with a frequency of one Hertz. Figure 21 depicts the integrated GPS downlink capability, which allows acquisition of the network, independent of the 2.4 GHz signal.

The Generation 2 payload was ready to be tested on both a balloon and a TERN UAV during the STAN 6 experiments at Camp Roberts from 02 to 05 May 2004. The following objectives drove the experiment:

1. Create a long-range network with airborne node
2. Integrate the long-range network into the Network Operations Center (NOC)
3. Find limitations and disadvantages of the airborne network

The test plan was structured as follows:

1. Test surrogate airborne node (balloon) for short (2km), medium (7km) and long range (12km)
2. Run Interference Exclusion Test with TERN taxiing on runway for safety reasons
3. Test tracking accuracy and link quality with TERN airborne
4. Find maximum range, K2 to TERN
5. Final test
6. Integrate ARIES (unmanned submarine) as second hop
7. Test for maximum range between ARIES and TERN (both omni antennas; 2-watt amplifiers); Have TERN take-off location different than K2 and Network Operations Center

Following the test plan, the first test phase took place in the vicinity of Lake Nacimiento with the three iterations of range extension.

3. Generation 2 Experiment

Table 6 provides a list of the established network nodes. Figure 22 illustrates the Surveillance and Target Acquisition Network (STAN), including the 2.4GHz 802.11b data links and the 900MHz Freewave GPS data link.

Node Name	IP Address	Description
Blue Tracking Unit	192.168.1.34	PC-104 in the K2
Blue Multicast Server	192.168.1.37	Provides broadcast of the a/c GPS position
Blue K2	192.168.1.72	802.11 bridge receiving data from K2 directional antenna
Blue TERN	192.168.1.74	not used
Blue Balloon	192.168.1.75	802.11 bridge in communications relay b
Blue ARIES (bridge)	192.168.1.76	802.11 bridge in ARIES vehicle
Blue Whaler	192.168.1.77	802.11 bridge onboard Whaler (ARIES host platform)
Blue PC104	192.168.1.78	ARIES Computer
Whaler Laptop	192.168.1.80	Laptop computer onboard Whaler
Blue mini-NOC	192.168.1.82-84	Laptops acting as mini-NOC receiving files from ARIES and used for management and performance assessment

Table 6. STAN Network Nodes

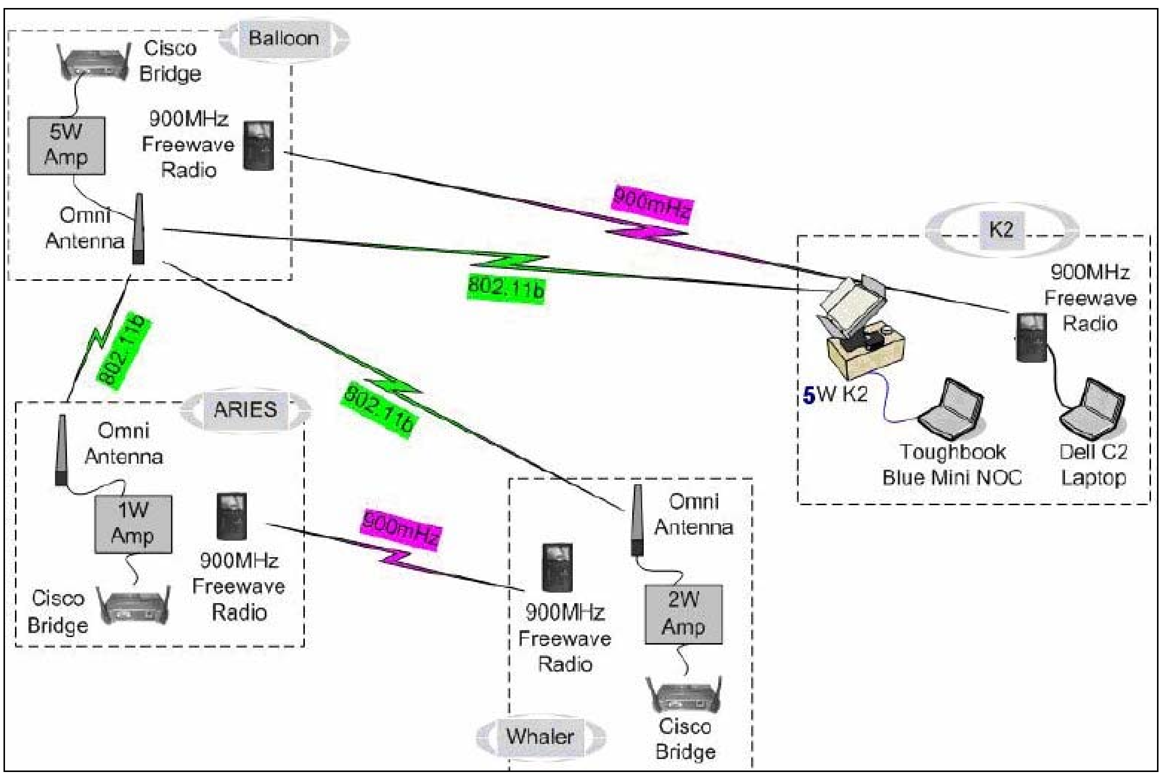

Figure 22. Generation 2 Network Architecture

4. Test Description and Results

Objectives during STAN6 were:

• Demonstrate high-bandwidth links for sonar and/or video file transfer between the unmanned vehicles ARIES AUV and TERN UAV, and the K2 located at Tactical Operations Center (Mini-NOC)

• Demonstrate 802.11b network links for AUV and UAV assets over distances greater than 4km at 200-300 kbps.

• Demonstrate the independence of the Mini-NOC from the Ground Control Station of the TERN and acquire connectivity “on the fly”

The operational requirements for developing this technology are stated as:

• Robust communications for command and control and data transfer are required for the warfighter deployed in an area. Autonomous Unmanned Vehicles can be used to scout and report on oceanographic conditions and the mine threat as well as serving as network nodes.

• Collected data is voluminous and requires a high bandwidth data link

• Data needs to be collected and distributed quickly for rapid operational planning

• Not all vehicles may return from missions – the data still needs to be collected.

The solution offered by this technology provides unmanned systems with high bandwidth communications (currently 802.11b) using a UAV as a bridge between an AUV and a command cell located some distance from the AUV.

The remainder of this section will provide a description of the tests and results.

Pre-Exercise Events.

ARIES was successfully ballasted and the ARIES Team completed a functional testing of subsystems. At that time, ARIES could not be controlled remotely. The 802.11b bridge was up and running.

The balloon was deployed and readied on top of Nacimiento hill which is close to Nacimiento Lake. This location allowed a maximum altitude of approx. 200m above the lake level.

Assembly of the TERN was completed and readied for a test flight. On Monday, 06 May the VC-6 Team balanced the TERN and conducted an initial test flight.

Exercise Results. Tests were conducted on 04 and 05 May to determine the range of the 802.11b link. Assessments of file transfer rates of various network configurations were also completed. These tests are described below.

Range Tests. On 04 May, tests were conducted between the network nodes to determine the range of the 802.11b data link.

Range Test One. Moving the location of the mini-NOC and K2 on a boat to the west on Lake Nacimiento varied the range of the network. On 04 May, a maximum three-node-link range of 7.45km was achieved between the K2 and the balloon flown from a hilltop. The distance between the balloon and ARIES was 1.98km. The tests were conducted between 1000hrs and 1400hrs Local. The weather was extremely dry and hot. Figure 23 illustrates the test geography.

Figure 23. Lake Nacimiento with Network Nodes

Range Test Two. On the same day, 04 May, a range test as shown in Figure 24 was conducted. A maximum link range was obtained with the mini-NOC and K2 at Camp Roberts, McMillan Airfield, approximately 11.5km from the balloon. Figure 24 shows the setup at McMillan Airfield. During these tests it was observed that the balloon was just above the horizon. The received 900MHz Freewave signal and network were of good quality (~250kbps).

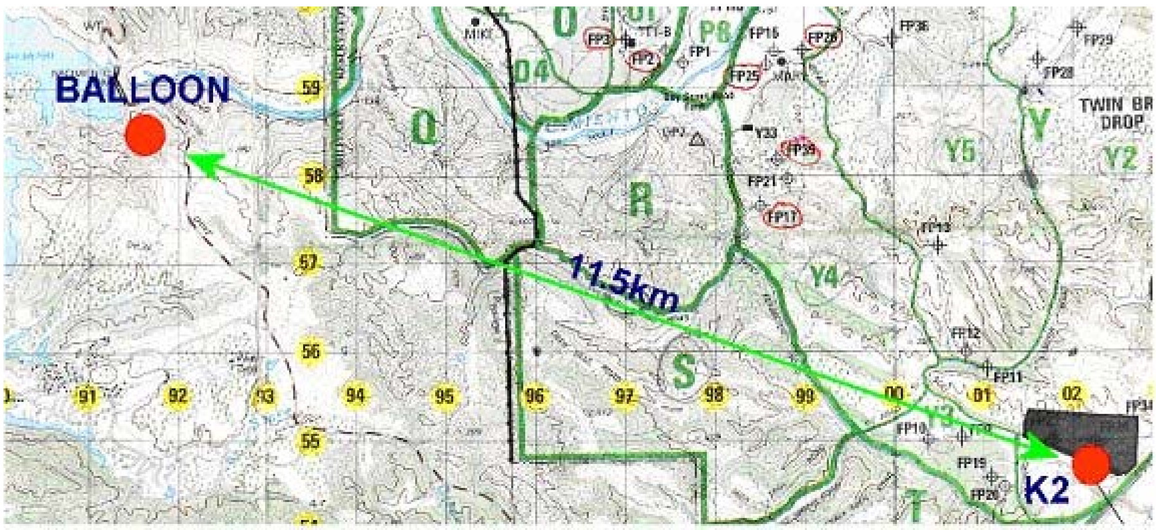

Figure 24. Geo-Locations of Network Nodes

EMI Test. In the late afternoon of 4 May, the EMI exclusion testing for the TERN was conducted on McMillan Airfield. TERN showed no effects on the 5W / 2.4GHz or the 1W / 900 MHz radiation while taxiing on the runway.

Tracking Test One. On 05 May a tracking test with TERN airborne was conducted. The network was up prior to take-off. Multiple flybys and an autonomous loiter up to 4km away from McMillan Airfield showed solid functionality of the tracking unit. Connectivity was never lost. Figure 25 shows the Mini-Noc with the K2.

Figure 25. Mini-NOC and K2 at McMillan Air Field

<u>Tracking Test Two</u>. Upon completion of Tracking Test One, VC-6 deployed to Tower Road, Camp Roberts. The Mini-NOC with K2 stayed at McMillan air field while ARIES, located in Lake Nacimiento, was readied to join the network. Figure 26 gives an overview of the locations. Green arrows indicate stable connectivity between the network nodes. The red arrow shows the flight path.

Figure 26. Final Tracking Test ARIES – TERN – K2

Shortly after TERN's takeoff the GPS multicast messages were received by the K2. The antenna initialized the tracking and connectivity with TERN was established at a range of ~6.5km. TERN then climbed and proceeded towards ARIES' position. ARIES was acquired by the Mini-NOC when TERN was approximately 5km from ARIES. It was observed that the link was not continuously stable due to the loss of line of sight between ARIES and TERN. Figure 27 shows the Mini-NOC network monitor indicating ARIES being dropped out but all other nodes connected. The upper left pane shows concurrent reach-back connectivity into the main Network Operations Center.

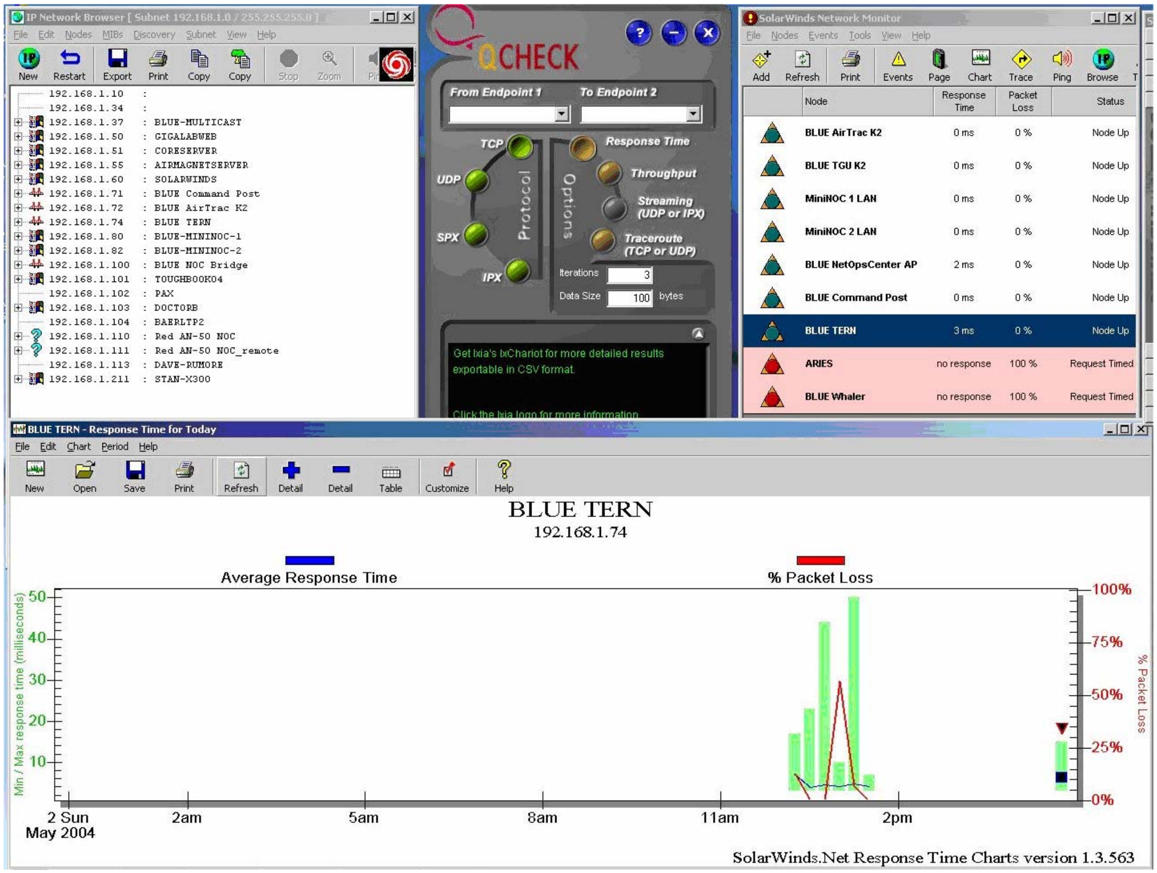

Figure 27. Network Monitor at Mini-NOC

At that time the difficulty of managing the airborne node (altitude and location) back at the Mini-NOC was discovered. Shortly before the landing, the power connector of TERN's 802.11b amplifier fell off and disconnected all other nodes early.

The TERN's front landing gear broke during the landing at Tower Road and the aircraft flipped over. Repairs were not possible during the experiment and the UAV could not be used any further.

5. Summary

The Aries/Tern mission was a qualified success. The mission demonstrated the ability to create a stable 802.11b network with three nodes with

a total length of 14.5km. Data files were moved along the network at file transfer rates ranging at a maximum of 800 kbps down to 300 kbps at maximum node separation.

The acquisition and tracking capability of the K2 was demonstrated independent and apart from the GCS of the TERN. The Mini-NOC was able to acquire TERN at any given location or time as long as the nodes were in line-of-sight. This is considered to be a milestone in the development work accomplished so far.

The low reliability of the TERN UAV was an important factor. Although rugged and designed for military applications, availability was always below expectations.

Regarding the network, future development will try to achieve higher bandwidth as well as develop a network management and awareness model for airborne network nodes.

C. GENERATION 3 (CAMP LEJEUNE, NC)

1. Evolution

Generation 3 was focused on developing a UAV awareness tool in order to facilitate guidance for the UAV pilot. Therefore, the networking part of the payload was not modified but a video transmitter (PELCO) was added. This transmitter converts and compresses an analog video signal into a TCP/IP packet stream. This packet stream in injected into the 802.11b network and received at the network center. There, a receiver decompresses and displays the video. Lab test in advance of the experiment showed adjustable, moderate network load from 85kbps up to 1Mbps depending linear to the video quality.

The goal was to display the live video from the onboard forward-looking lipstick camera of the UAV in combination with a map that showed an icon of TERN’s geographic location, course, speed, and altitude. A facilitator would then be able to communicate on a voice line to the pilot’s coordinator where the UAV was to be relocated in order to maintain connectivity.

2. Test Description and Results

Table 7 provides a list of the CJTFEX 04-2 network nodes. Figure 28 illustrates the CJTFEX 04-2 network, including the 2.4GHz 802.11b data links and the 900MHz Freewave GPS data link.

Node Name	IP Address	Description
Blue Command Post	192.168.1.71	not used
Blue K2	192.168.1.72	802.11 bridge receiving data from K2 directional antenna
Blue TERN	192.168.1.74	not used
Blue Balloon	192.168.1.75	802.11 bridge in communications relay b
Blue ARIES (bridge)	192.168.1.76	802.11 bridge in ARIES vehicle
Blue Whaler	192.168.1.77	802.11 bridge onboard Whaler (ARIES host platform)
Blue PC104	192.168.1.78	ARIES Computer
Whaler Laptop	192.168.1.80	Laptop computer onboard Whaler
Blue mini-NOC	192.168.1.82	Laptop acting as mini-NOC receiving files from ARIES

Table 7. CJTFEX Network Nodes

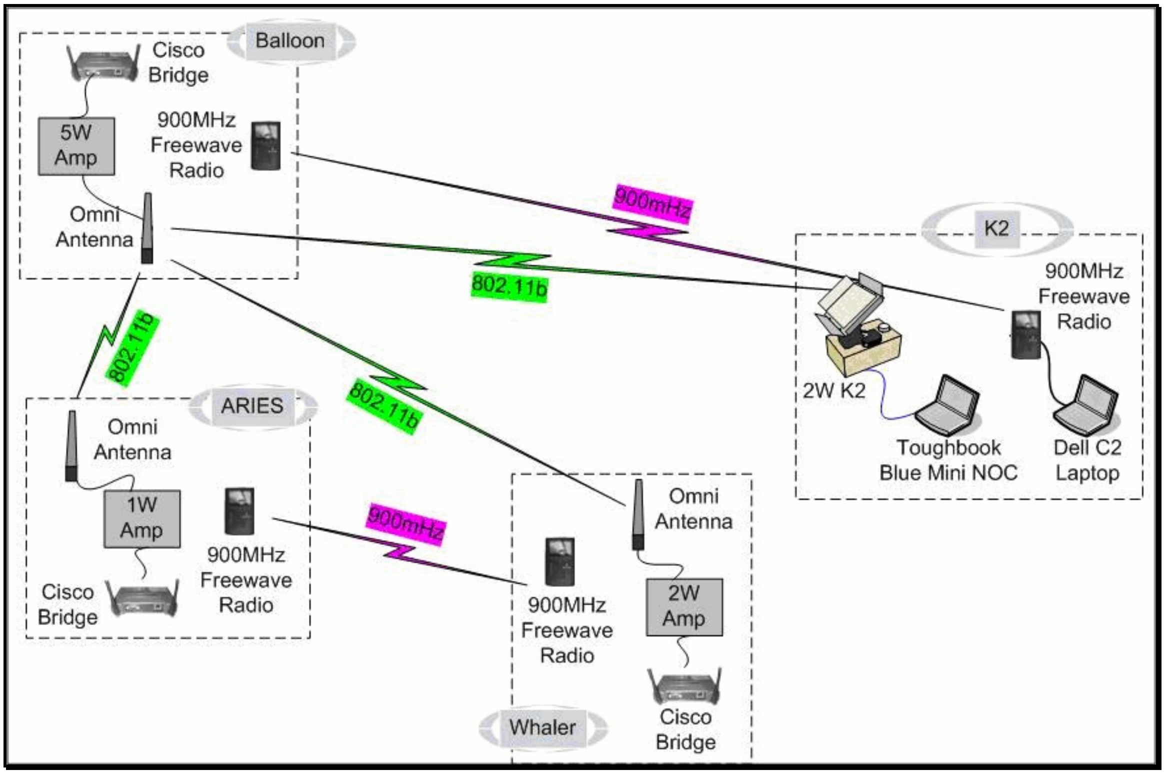

Figure 28. CJTFEX Network Architecture

<u>Objectives</u>

Demonstrate high bandwidth links for sonar and/or video file transfer between the ARIES AUV, the TERN UAV and the K2 Tactical Operations Center

Demonstrate 802.11b network links for AUV and UAV assets over distances greater than 4km at 200-300 kbps.

The operational requirements for developing generation 3 are:

- Robust communications for command and control and data transfer are required for teams of vehicles deployed in an area to scout and report on oceanographic conditions and the mine threat.
- Collected data is voluminous and requires a high bandwidth data link.

- Data needs to be collected and distributed quickly for rapid operational planning.
- Not all vehicles may return from missions – the data still needs to be collected.

The solution offered by Generation 3 provides unmanned systems with high bandwidth communications (currently 802.11b) using a UAV as a bridge between an AUV and a command cell located some distance from the AUV. The technology also automates the path of the UAV to optimize the link between the groups of vehicles.

The remainder of this section will provide a description of the tests and results.

Pre-Exercise Events

On Thursday, 05 June, the ARIES was successfully ballasted and the NPS Team completed a functional testing of subsystems. Assembly of the TERN was completed and it was readied for a test flight. On Friday, 04 June, the NPS Team conducted a tow test of ARIES using Guard Boat Four. Maximum tow speed was six knots, though higher tow speeds were eventually used (up to 7 knots). On Saturday, 05 June, the TERN crashed during its first test flight (see Figure 29). Due to the TERN crash, the balloon acted as a surrogate UAV during the entire exercise.

Figure 29. TERN Crash

Exercise Results. Tests were conducted on 07 and 09 June to determine the maximum range of the 802.11b link. Tests were conducted on 06 and 08 June to determine the file transfer rates of various network configurations. These tests are described below.

Maximum Range Tests. On 07 and 09 June, tests were conducted between the network nodes to determine the maximum range of the 802.11b data link.

Maximum Range Test One. Moving the location of the mini-NOC and K2 to the south along the North Carolina shoreline varied the range of the network. On 07 June, a maximum two-node link range of 18.9km was achieved between the K2 at North Topsail Beach and the balloon flown from near the South Tower at Onslow Beach. The tests were conducted between 1315hrs and 1400hrs Local and the weather was extremely humid and hazy. The K2's position was 34°27.652'N, 077°29.082'W and the balloon's position was 34°32.792'N, 077°18.375'W. Collected data and screenshots are provided in Appendix A. Figure 30 illustrates the test network and Figure 31 shows the test geography.

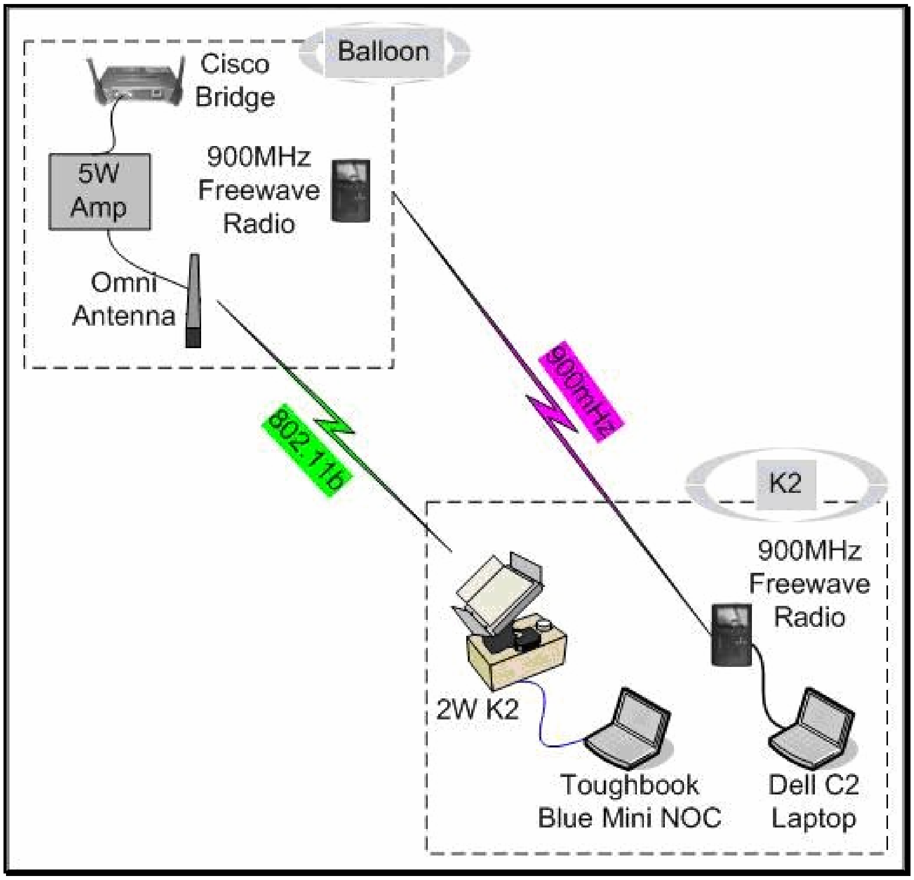

Figure 30. Maximum Range Test 1 and 2 Network

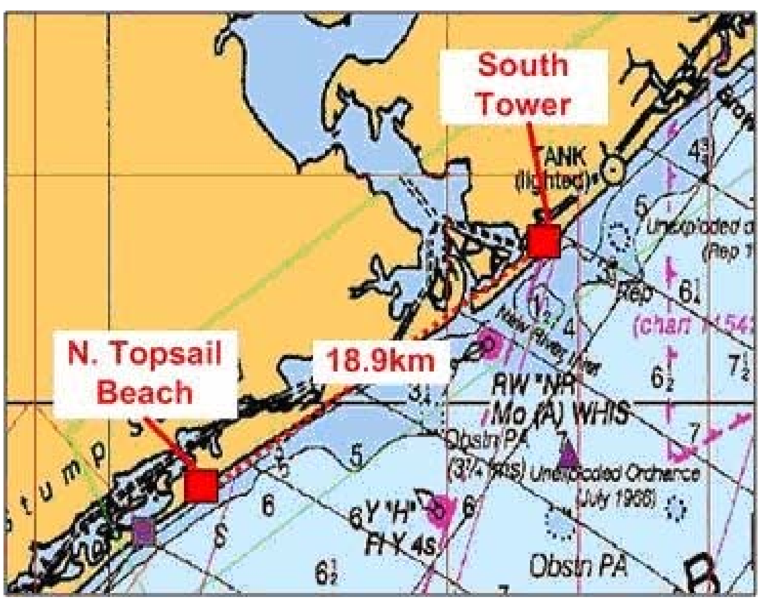

Figure 31. Maximum Range Test 1 Geography

Maximum Range Test Two. On 09 June, the Maximum Range Test of 07 June was repeated, using the network as shown in Figure 30. The weather was less humid and hazy. First, a maximum link range was obtained with the mini-NOC and K2 at North Scotch Bonnet Beach, approximately 19.9km from the balloon at South Tower, as shown in Figure 32. During these tests it was observed that the manually set position of the K2 was critical for link quality. Small changes in both bearing and azimuth produced significant changes in link quality.

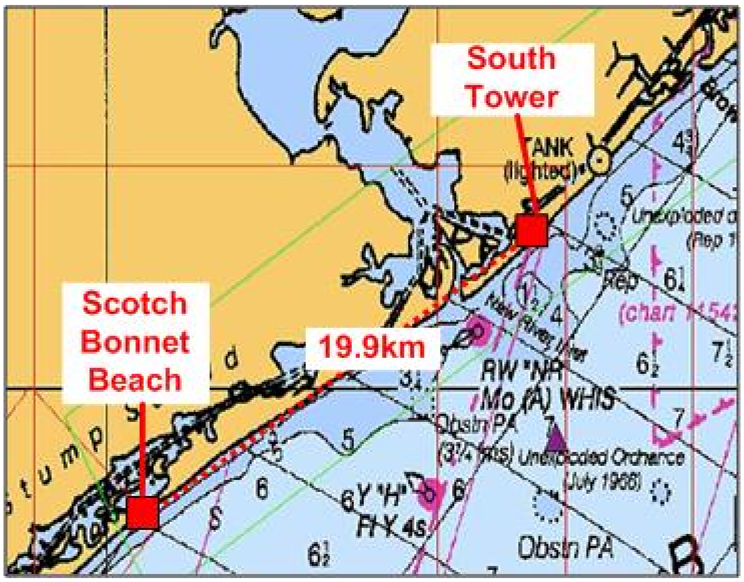

Figure 32. Maximum Range Test 2 Geography

Maximum Range Test Three. After the maximum K2 range was established, the next step was to discover the maximum range of a three-node 802.11b network between the mini-NOC K2 and the Whaler, with the balloon acting as a network communications relay (see Figure 33). The K2 was moved in to the North Topsail Beach location (34°27.650'N, 077°29.083'W) at a range of 18.9km from the balloon at South Tower. This range was the maximum distance where a stable link could be established on this day between the K2 and the balloon. The Whaler then took position at 2.5km seaward from the balloon. A network link was successfully established and a set of three ARIES video files was transferred from the Whaler laptop to the mini-NOC laptop using Microsoft

Windows file sharing (drag and drop between Windows folders). The file transfer time was measured and the file transfer rate in kbps was calculated for each run. The test continued with the Whaler increasing its range to seaward from the balloon in approximate 1-km increments. The maximum 802.11b link range between the Whaler and balloon was 8.0km as shown in Figure 34.

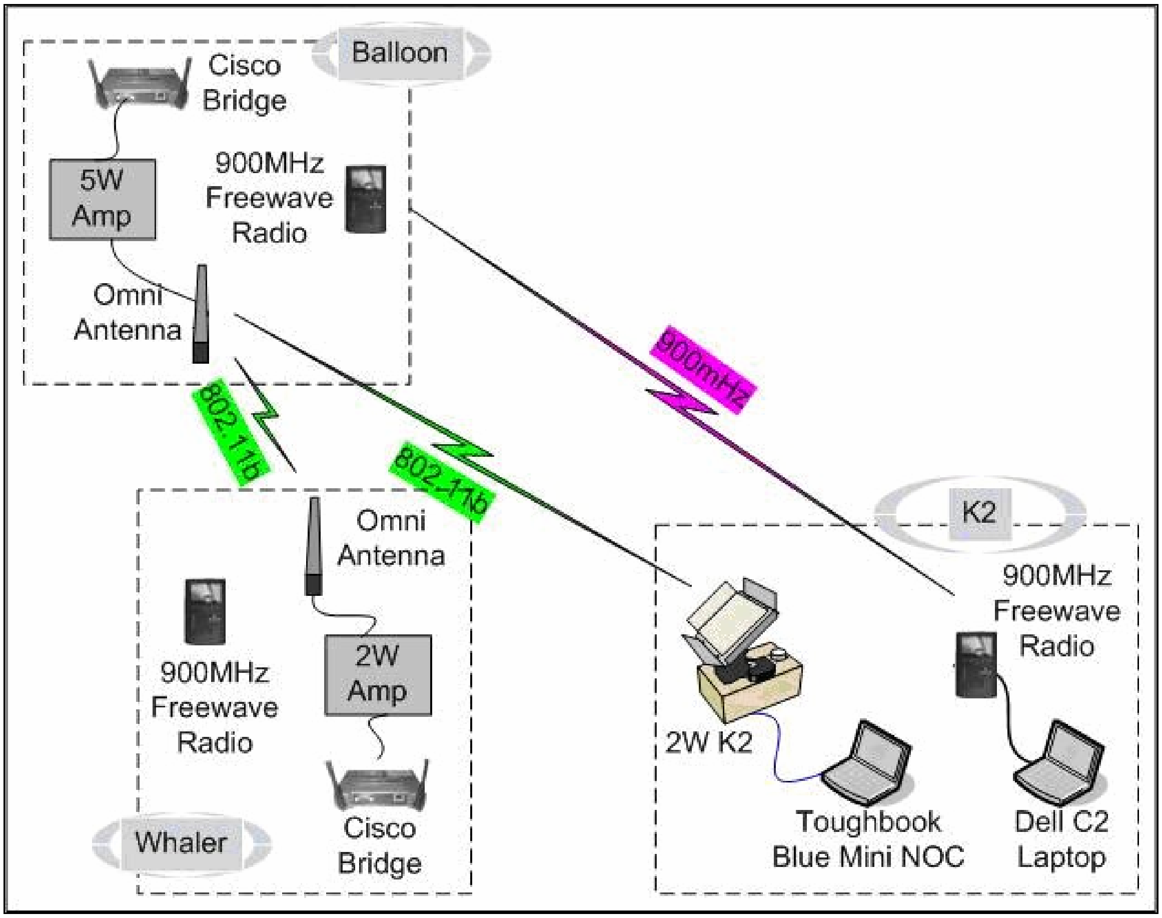

Figure 33. Maximum Range Test 3 Network

This test resulted in a maximum three-node link range of 26.9km from the mini-NOC K2 to the Whaler using the balloon as an airborne relay node. File transfer rates at this maximum range averaged 160kbps for the three runs. It is anticipated that the link range and file transfer rates were limited by the hazy and humid atmospheric conditions and also by the 1000-ft. maximum elevation of the balloon. Also, there was limited time to optimize the various settings of the Cisco

802.11 bridges, so the settings may have been sub-optimized for this particular situation. Further testing is planned and ranges beyond what was obtained in this test should be possible, although the 26.9km range obtained during CJTFEX 04-2 greatly exceeded expectations.

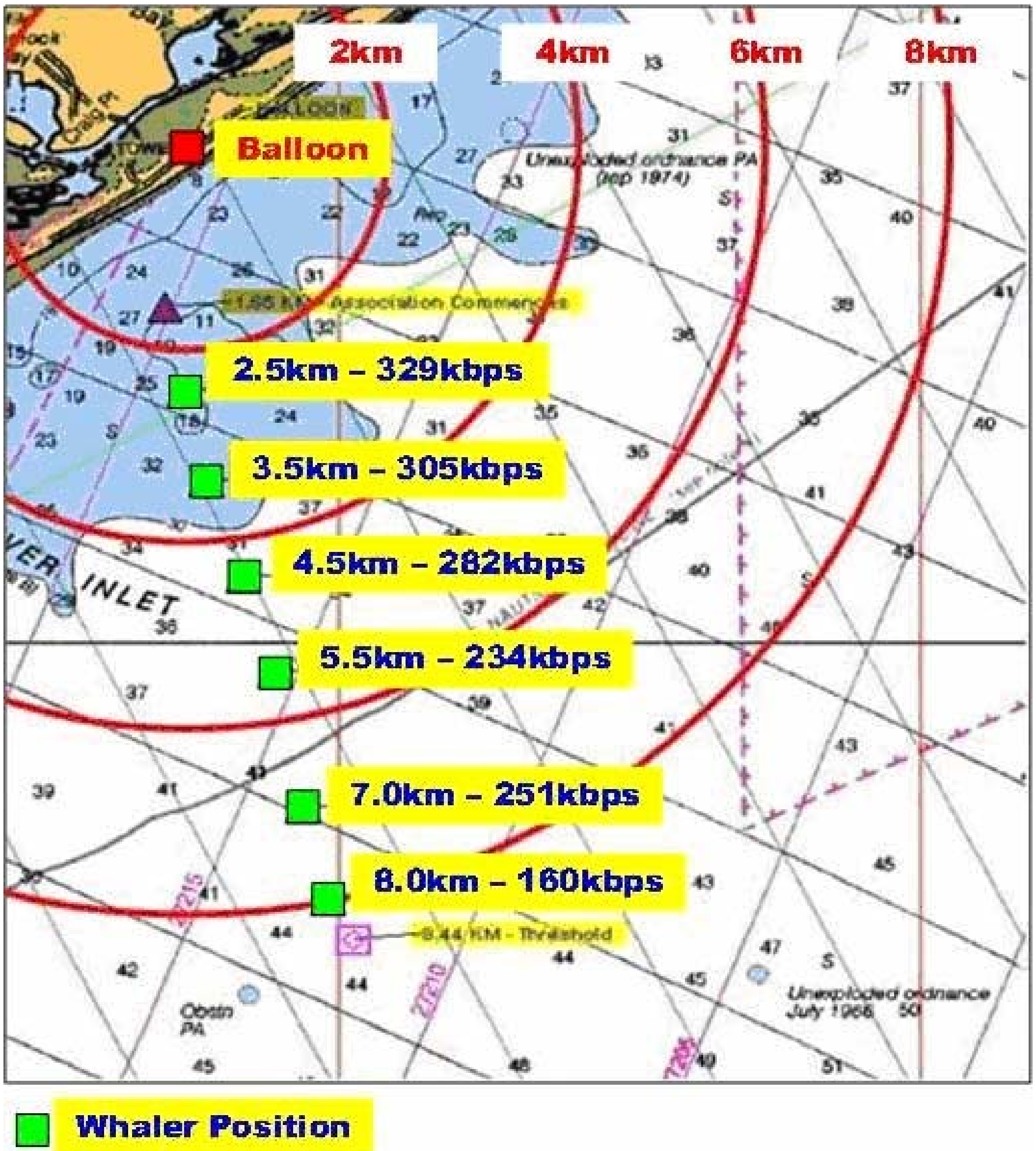

Figure 34. Maximum Range Test 3 Results

Data Transfer Tests. On 06 and 08 June, tests were conducted between the mini-NOC K2 and the ARIES to determine file transfer rates over the 802.11b data link.

Data Transfer Test One. The first set of tests on 06 June verified the ability of the network to transfer files at short ranges. The Whaler and ARIES were located in Mile Hammock Bay, just off Landing Zone (LZ) Bluebird. The mini-NOC with K2 was located at LZ Bluebird several hundred meters from the Whaler. Both nodes were approximately 2km from the balloon at South Tower, which was at approximately 187m altitude above mean sea level (MSL). The K2 operator then retrieved ARIES video files (2.796MB and 7.657MB in size) from the PC104 Data Acquisition Computer onboard ARIES using Windows file sharing. An average file transfer speed of 350kbps was achieved. The network was as depicted in Figure 33.

Data Transfer Test Two. The second set of tests on 06 June extended the range of the mini-NOC K2 from the balloon out to the parking lot outside the LWTC, approximately 15.5km from the balloon. The balloon altitude was also raised to 342m. The network was as depicted in Figure 33. The test geography is shown in Figure 35.

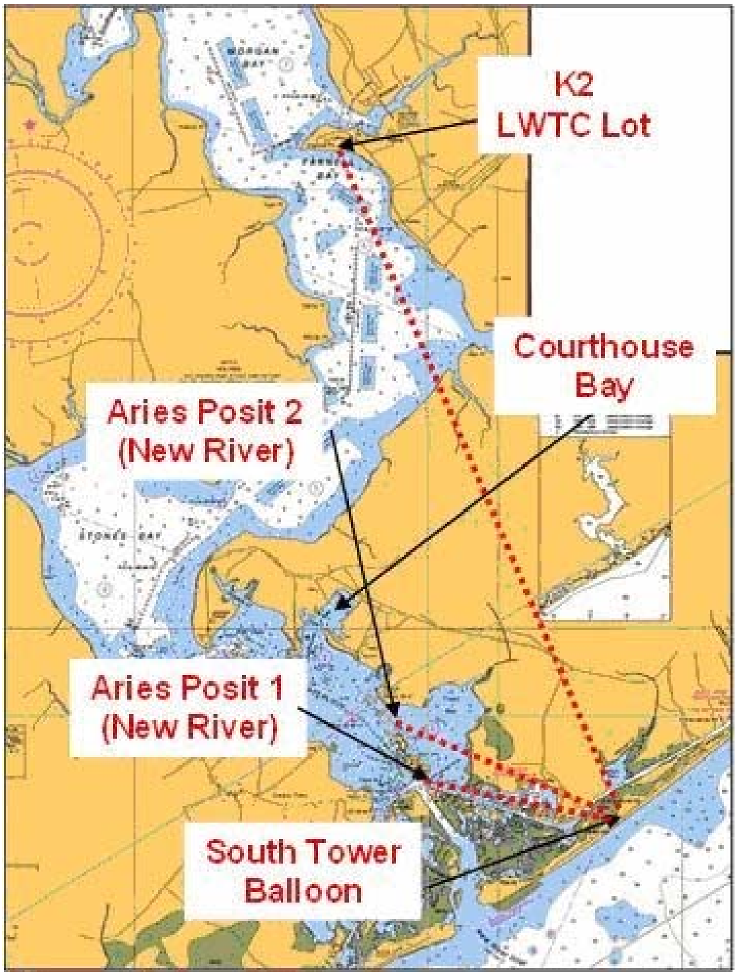

Figure 35. Data Transfer Test 2 and 3 Geography

During this test it was observed that moving the K2 from LZ Bluebird to the LWTC increased the link range. A 72.6% increase in average file transfer rate occurred (average of 604kbps vs. 350kbps). This is due to the radiation pattern of the antenna used on the balloon, which disallows good signal quality right below the balloon (see also figure 17, radiation patterns).

While the balloon was being lowered, link degradation was observed. At 150m altitude, a solid link was still observed. At 100m altitude, a 3% packet loss was observed. By the time the balloon reached 77m, a rapid increase in packet loss was observed. At 65m the link was lost.

Data Transfer Test Three. The third set of data transfer tests were conducted on 08 June. Because of a fault in the ARIES, files could not be retrieved from the ARIES computer, so the Whaler laptop was used as a surrogate. The test consisted of the mini-NOC K2 node at the LWTC parking lot, the balloon at South Tower and the Whaler in New River, as shown in Figure 35. It was observed that the Freewave link was lost when helicopters flew over the mini-NOC site, probably due to some RF transmissions that interfered with the 900MHZ Freewave link. The link would be restored after the helicopter passed.

Also during this test, a streaming video test was conducted. A 7.657MB video file was executed on the Whaler laptop from the mini-NOC laptop using Windows file sharing. The video file was played on the mini-NOC laptop over a period of 168 seconds, although the native file real-time length was much less. The video seemed to play continuously, although slower than expected.

Post-Exercise Events. Thursday, 10 June was spent on exercise debriefs at the Littoral Warfare Training Center (LWTC) and at an exhibit of exercise systems at Courthouse Bay.

3. Summary

The NPS Aries/Tern mission was a qualified success. The mission demonstrated the ability to create a stable 802.11b network with three nodes with a total length of 27km. Data files were moved along the network at file transfer rates ranging at a maximum of 800 kbps down to 160 kbps at maximum node separation (max range).

As stated in Section 1.0, the primary objective of these experiments was to assess the military utility and application of participating systems in a real-world exercise environment. It appears that 802.11b technology does represent one means of providing a high bandwidth (200 to 800kbps) link between autonomous and unmanned vehicles and other network nodes using standard Windows networking. The architecture is relatively simple to set up, uses COTS components, and is relatively secure. A significant drawback is that 802.11 can easily be jammed.

The secondary objective was to collect information to evaluate how these systems can be better integrated onboard the military host platforms. Because of the relatively small and lightweight components involved, this 802.11b data architecture could fairly easily be integrated into existing and future UAVs and AUVs. The biggest weight concern comes from the batteries. The length of mission operating time required dictates the size and weight of the batteries. The command part of the system should easily be integrated into a Modular Mission Package (MMP) design, though this was not investigated as part of this exercise.

The third and final objective was to collect information to enable an assessment of individual system performance, thereby marking development progress and capability using standard measures of performance and effectiveness.

Hardware problems, including the crash of the TERN AUV and the failure of the ARIES DVR, prevented the mission from demonstrating all of the functionality intended for the exercise. The TERN aircraft would have enabled a demonstration of greater network ranges due to its ability to fly higher than the balloon. The presence of the TERN also would have enabled the demonstration of the K2 unit's tracking mode, a significant feature. The absence of the ARIES digital video recorder (DVR) prevented only the demonstration of the capability of the system to obtain underwater video imagery and then transfer stored video to ARIES' PC104 computer. Pre-stored video files were transferred along the network instead.

Despite the hardware issues, the NPS experiment package successfully built upon prior experiments and demonstrated a reliable, secure and robust network connecting UUV platforms with the mini-NOC/TOC at the K2. This network allows COTS functionality and support and permits the operator to access real-time sensor data in remote locations. Like many COTS wireless applications, the use of the commonly available 802.11b spectrum is subject to jamming or unintentional interference and provides the greatest use in connecting sensors in remote locations. However, 802.11b technology is a

viable and effective means of transferring large files and streaming data feeds and is well suited for unmanned and autonomous vehicles. Future testing, most immediately at the STAN 7 experiments set for 19-24 August 2004 at Camp Roberts, California, will provide an opportunity to demonstrate these capabilities and continue expanding the network capabilities. Future demonstrations would include additional network nodes, multiple sensor output formats, greater network ranges and optimization of 802.11b link settings. It is also recommended that newer technologies such as 802.11g (54Mbps) and Orthogonal Frequency Division Multiplexing (OFDM) be researched.[10]

Finally, the utilization of an alternative aircraft and optimization of the hardware with regard to weight and power draw are recommended research goals for future generation payloads (STAN 7).

[10] Marshall & Valdes, Office for Naval Research, 2004

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V. NETWORK MANAGEMENT AND MONITORING

A. NETWORK MANAGEMENT

This chapter embraces the area of network discovery, monitoring and management. The split among these three subcomponents follows the sequence of how networks are established and maintained. The reader can also find a description of the evolved, most useful and compact version of the network operations center for managing and maintaining the airborne unmanned aerial vehicle network.

1. Network Discovery

Network discovery starts at the point where the operator(s) thinks the setup is complete. For the inherited complexity of wireless networks and the limited capability to fix thing “on the fly”, careful measures have to be taken to ensure that everything is in place and working.

Initial connectivity checks can be performed with simple pings or--better and more conveniently--with a discovery tool like Solarwinds. Figure 36 shows the expanded BLUE MININOC-1 node with the active network interface ”ORINOCO 802.11g”.

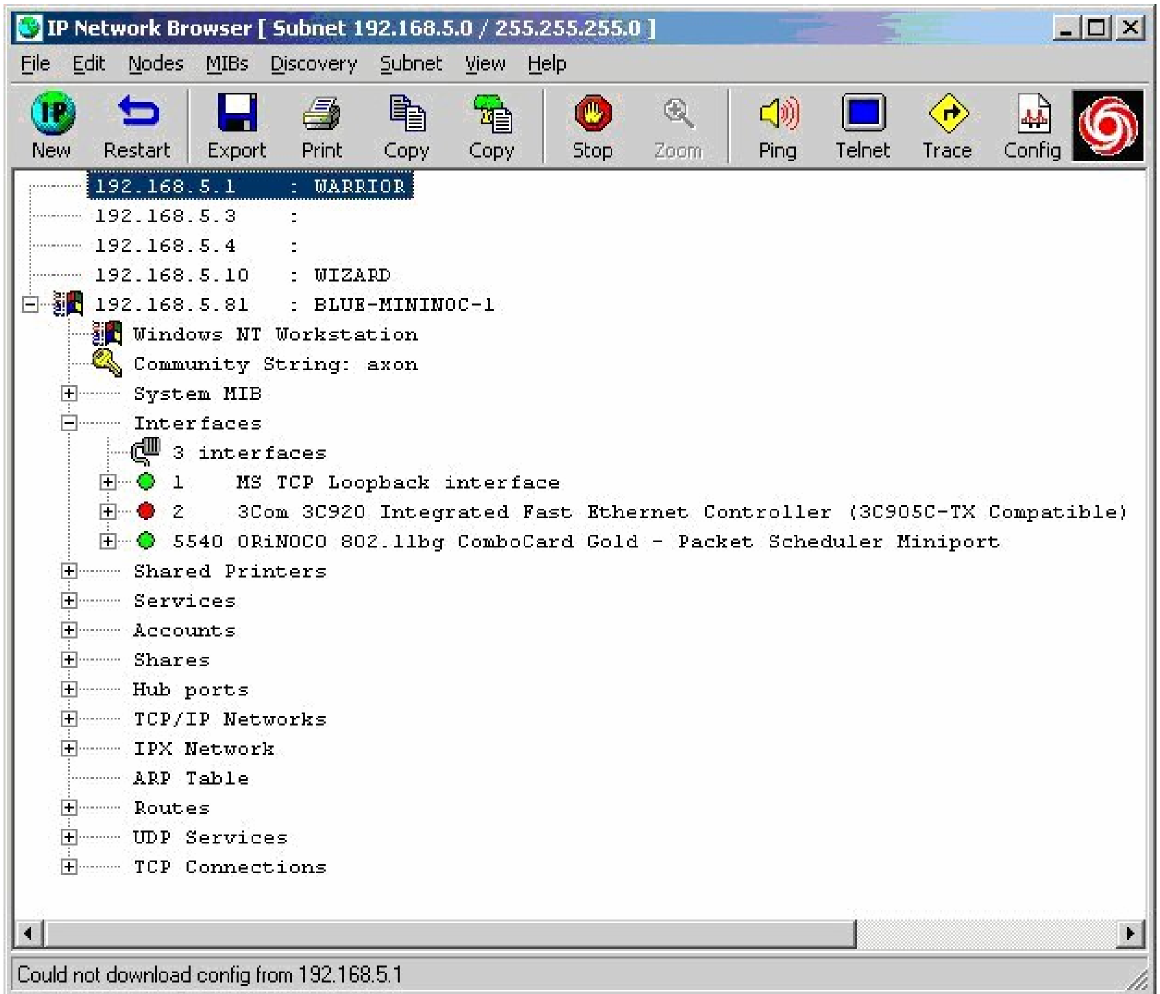

Figure 36. Solarwinds Network Browser

The shown network browser also allows the investigation of the node's properties when the simple network management protocol is enabled on that specific machine. It was found very useful to identify the network node properly in order to verify that all planned connections were enabled. For security reasons, the community string was set to a very uncommon word in order to deny network mapping to an assumed adversary.

A wireless network can be physically detected with simple free software tool like Netstumbler, which displays the signal-to-noise ratio versus geographic location including a time stamp. It is extremely useful to detect the remaining signal strength of a known network for the purpose of maximizing range and optimizing

link quality. For that to happen, one would connect the used antenna and amplifier to the data-reading wireless card and, as a result, the S/N ratio and a possible GPS location would be recorded. Figure 37 shows Netstumbler while recording.

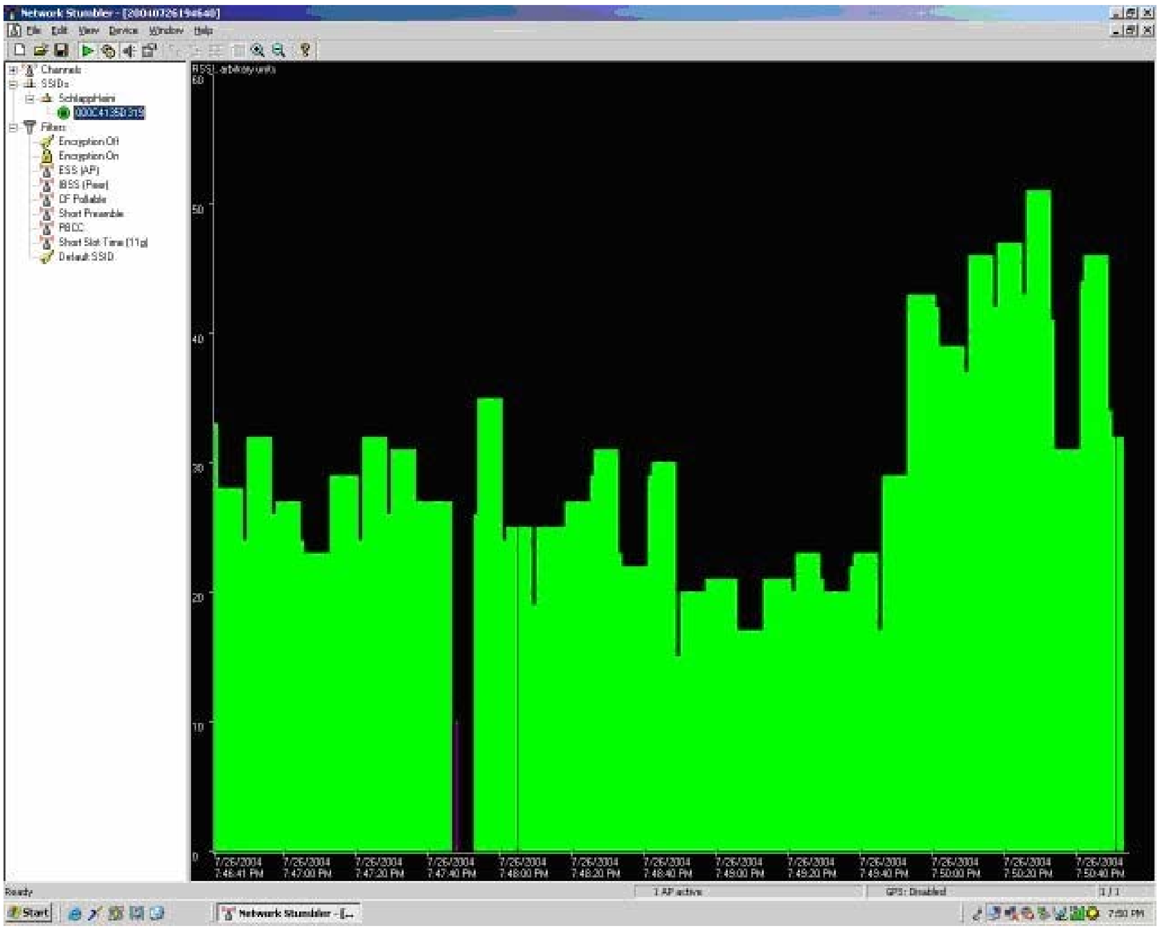

Figure 37. Netstumbler Displaying Signal Strength vs. Time and Geo Location

An alternative to Netstumbler is the AIRONET 350 client software installed on the Tacticomp from INTER-4 which allows site-survey for link quality and field strength. The Tacticomp (Figure 38) is a rugged, military-version PDA, with integrated GPS and amplified 802.11b client radio. Although much more convenient in the field, a mapping of the GPS location versus the signal strength

cannot be easily accomplished. The Tacticomp was mainly used for a quick look at network quality and field strength or to simply ping another node.

Figure 38. Tacticomp for Network Discovery

2. Network Maintenance and Management

Once all network nodes are discovered, the network operator switches to maintenance mode. This entails continuous monitoring of link quality in order to detect possible interruptions. A key element is the Simple Network Management Protocol which allows the monitoring of the exact throughput of every single node. Throughput degradation is the first indicator of network failure and needs careful attention. Figure 39 shows Solarwinds monitoring a network node during file transfer.

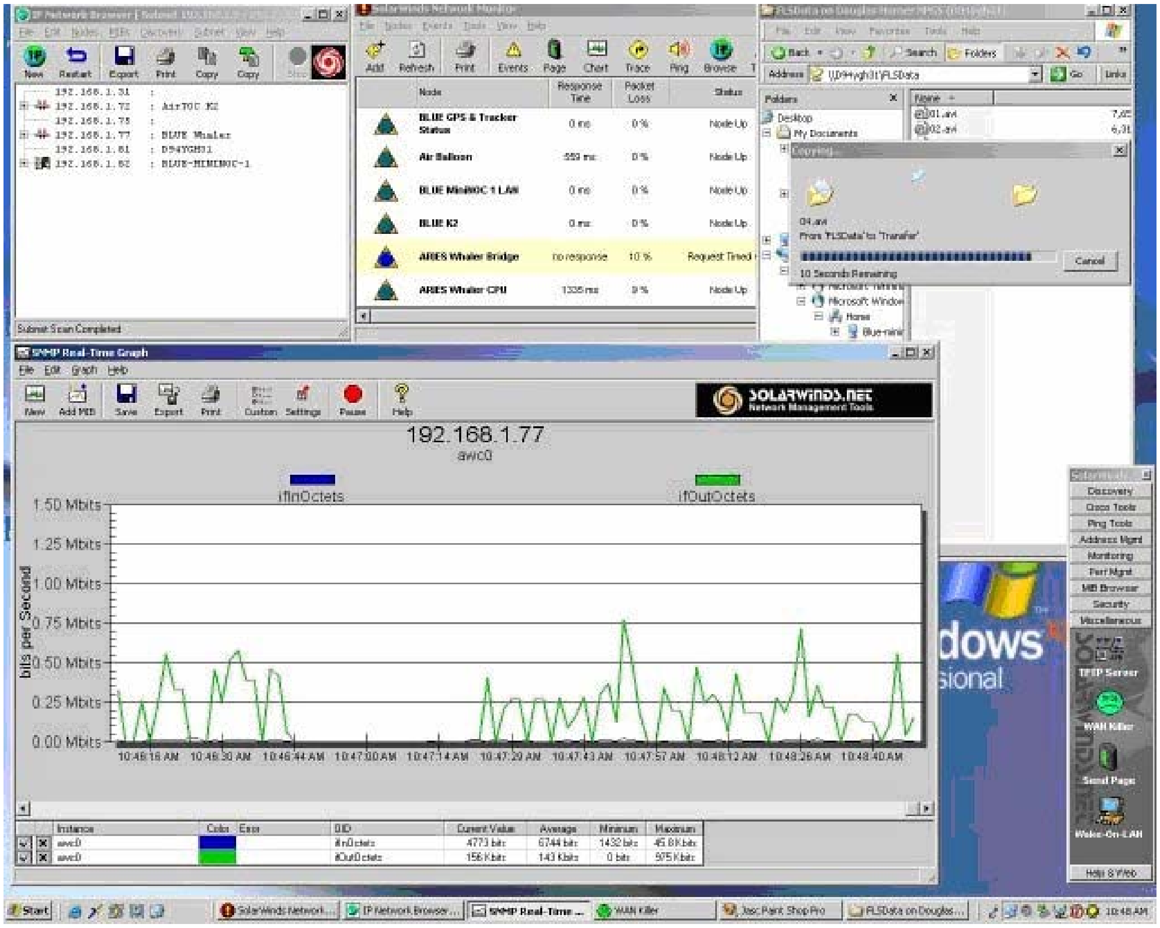

Figure 39. **Solarwinds monitoring 192.168.1.77 during file transfer**

In case network failure is detected, the operator will try to reestablish the connection by remote adjustment of the last working piece of equipment in the network chain. If remote adjustment is unsuccessful, a mobile node needs to go out to the equipment suspected of having failed. This method is fully valid for static network nodes but of only limited applicability to mobile nodes, since the reason for failure is very often the loss of line-of-sight between the communicating nodes.

An in-depth explanation of the problem and a possible solution is described in section B, UAV Awareness and Management.

3. Network Operations Center versus Mobile (Mini) NOC

In order to execute the actual network monitoring and management, a network operations center needs to be set up and operational. Screens for network discovery, monitoring nodes for throughput, processor load and other technical data is possible using SNMP. A relatively large center as shown in figure 40 has the opportunity to allow room and displays for tactical operations and decision support. The limit of functionality is set by available space and equipment.

Figure 40. Network Operations Center for STAN experiments

The disadvantage of this type of installation is that it cannot move; its location is fixed. Especially for remote operations where the far end is only temporarily connected through the UAV, a downsized, portable network operations center is needed. For that purpose, the views used in the big operations center were adjusted and rearranged in such a way that they fit laptop screens and do not rely on landline power. Figure 41 shows the solution in the back of a SUV, allowing the discovery, monitoring and management of the UAV network node and the interconnected backbone.

Figure 41. Mobile Network Operations Center for UAV Network

Guidance of the UAV for the purpose of network maintenance was first learned at that time. UAV awareness for the network operator, as shown in figure 41, was executed via voice and was immediately recognized as inefficient. The identified need is partially implemented in Generation 3 but definitely an area for further research. The experienced difficulties of managing and facilitating a network, especially with an airborne node, are discussed in the following section.

B. UAV AWARENESS AND MANAGEMENT

The perspective from the viewpoint of the network operator or, respectively, the facilitator, allows particularly clear insight into identifying the problem area of managing a UAV network node.

One of the major objectives at STAN 6 was to test the long-haul airborne network from the NOC to the AIRES AUV in Lake Nacimiento, approximately 12 km away. The TERN UAV acted as a LOS relay between the two locations. Reachback from the AIRES to the TERN to the NOC was through a wireless 802.11b network. GPS data on the UAV fed through a 900 MHz radio network

back to the NOC, and was displayed on a laptop. In addition to the performance, configuration, and fault input available to the facilitator, the GPS input was vital to knowing the location of the TERN. Connectivity from the NOC to the TERN was strong and stable due to clear LOS. However, the LOS between the AIRES and the TERN remained a problem. Feedback from the NOC operators informed the facilitator that as the TERN circled its flight path, the AIRES connection was consistently lost in the same arc of the path. Using maps and GPS to determine where the TERN was flying, the facilitator realized that the lost connectivity was due to a large hill obstructing the LOS between the AIRES and the TERN. Figure 42 is the SolarWinds Network Monitor view of the network; it informed the facilitator that the AIRES node dropped off the network and could not reach back to the NOC.

This fault management view of the airborne network showed that the bridge and CPU in the AIRES were both down. The performance management graph in Figure 42 pertains to the throughput in and out of the TERN. The top line in the graph shows that data was flowing out of the aerial node to the NOC because a connection was established between the two. But there was no connection between the AIRES and the TERN, which is indicated by the bottom line showing negligible throughput coming into the aerial node. The screen shot was taken when the hill obstructed the LOS between the AIRES and TERN. After assessing the network situation, the facilitator made a decision to fly the TERN higher, so the hill was no longer an obstruction. If there were uncertainty about how high the UAV should fly, the pilot could test its flight path one full revolution to see if the connectivity is stable.

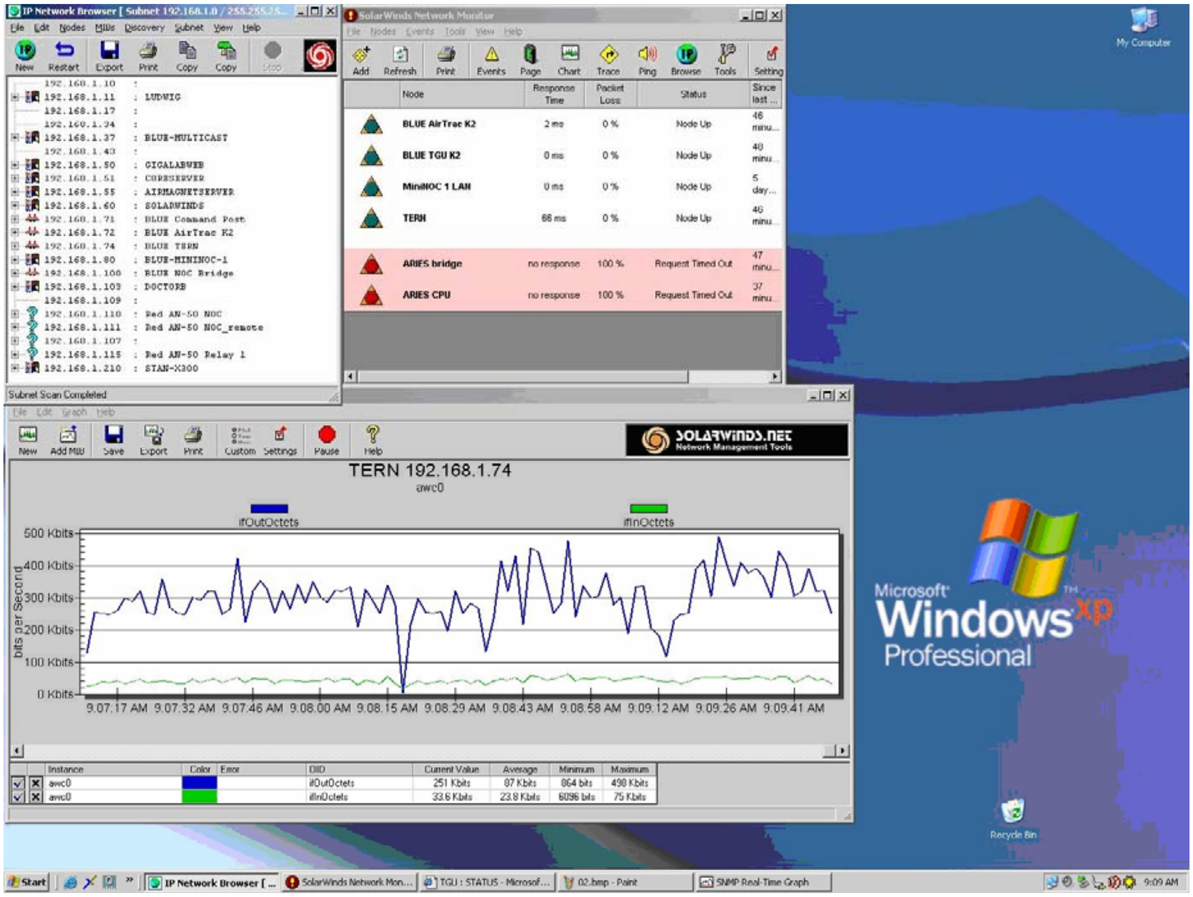

Figure 42. UAV Input Before Action

The network monitor (Figure 43) shows that the connection to AIRES was reestablished with minimal packet loss. Reach-back to the NOC was tested with a file transfer originating from the AIRES. The performance management graph shows that the throughput lines in and out of the TERN are virtually identical, which indicates solid connectivity and successful file transfer.

Figure 43. UAV Input After Action

The identified difficulties led to a significant improvement in the awareness of the aircraft's status and ability to maintain network performance in the follow-on Generation 3. The idea is that the detached small-network operations center (mini-NOC) needs to be able to receive a live video feed. This greatly enhances the awareness of the status of the UAV as well as allowing the depiction of the UAV's location in conjunction with the GPS data. In particular, a 3-D application using terrain data allows the determination of whether line of sight between the K2 and the UAV is given or not. By the time this thesis was completed, no suitable application was discovered that would serve the envisioned purpose. Figure 44 shows a possibility for displaying the profile between network nodes in a static manner. If the terrain profile could be updated in real-time, it would allow assessing the line of sight at any given moment in time as long as the GPS data

is received. In the shown example, the red line (between TERN and ARIES) would indicate a broken link due to the loss of line-of-sight.

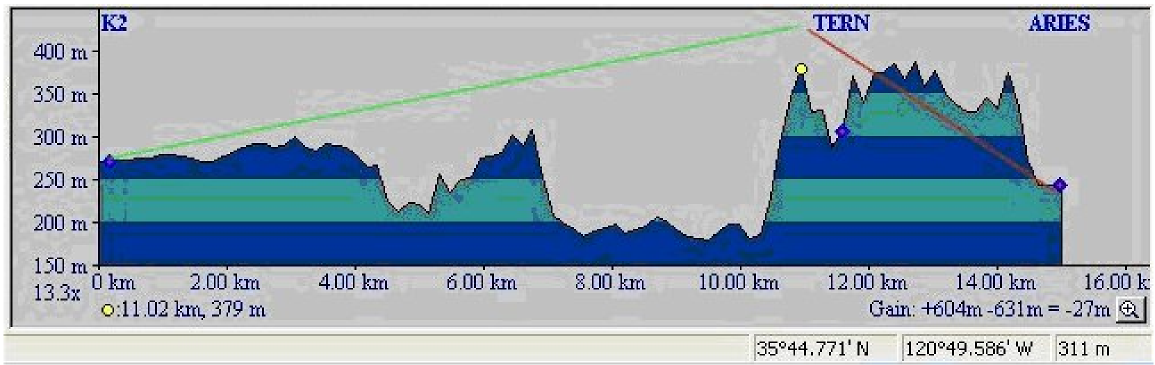

Figure 44. Static terrain profile between network nodes

The actual embedded awareness for Generation 3 included navigation software that allows display of the UAV's location in 2D. The data is acquired from the same free-wave link that is used to generate the multicast GPS messages that direct the K2 antenna to point towards the UAV's position. A status window displays speed, heading and the position in Lon/Lat. This data in combination with the live video feed of the forward looking camera of the UAV allows real time observation of the movements of the UAV (e.g. banking, nose diving etc.) These movements were observed to degrade the network link when exceeding angles of ~50 degrees, although no quantitative experimental analysis was conducted.

Due to that fact, UAV awareness was prioritized for Generation 3. Tested on the balloon only, but fully valid and useful for any mobile airborne node, the display of the UAV awareness for the network operator is shown in figure 45.

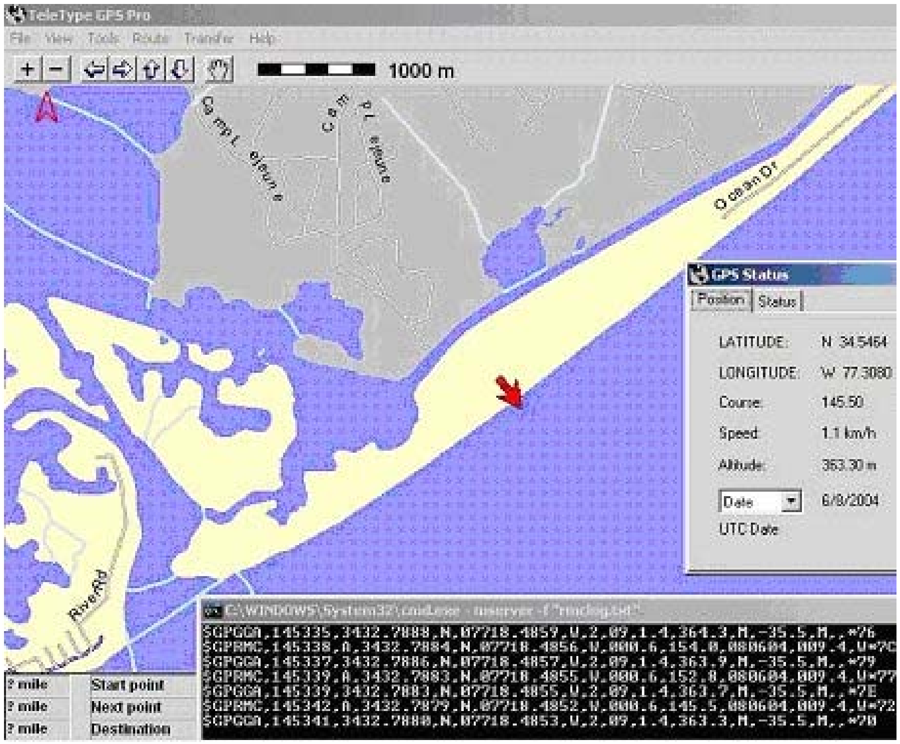

Figure 45. UAV Awareness for the Network Operator

An icon for the location of the UAV is placed over a map of the geographical area. The status window shows geographical position, course, speed and altitude of the UAV. The command line window shows raw GPS data coming in via the 900MHz freewave in order to determine the quality of the freewave link. In addition, the live video feed from the UAV's camera will allow for the continuous assessment of the overall movement of the aircraft, which might also be a reason for link quality degradation.

Once a link failure is detected, the network operator is able to determine excessive range or loss of line of sight as a possible reason and redirect the UAV via a voice channel to the pilot's supervisor. An envisioned system for warning the pilot directly would check whether the geometric line between the tracking antenna and the UAV "hits" the terrain. An adjustable conical shape of that line with it's origin at the antenna could warn the pilot directly. An integration of this warning functionality into the mission planning system for the UAV would allow for consideration of the LOS issue ahead of time. While this thesis is published,

Dr. Wolfgang Baer and the author are working on the realization of this system named Signal & Network Attenuation Predictor (SNAP). The only inputs this system will need are the geographical locations of the UAV and the antenna. The visualization of the LOS, the moving icon of the UAV and the perspective 3-D terrain view are derived from the terrain data stored on the processing platform. Figure 46 shows a red cone originating at the antenna and pointing toward the UAV located in the center of the black elliptic circle. The blue area indicates the terrain that might prevent proper network operations. The pilot could react on this prediction by increasing the altitude and the warning would disappear. The envisioned system would enable the UAV pilot to maintain link quality without any third-party communications. Testing of the prototype is planned during the STAN 7 experiment in August 2004.

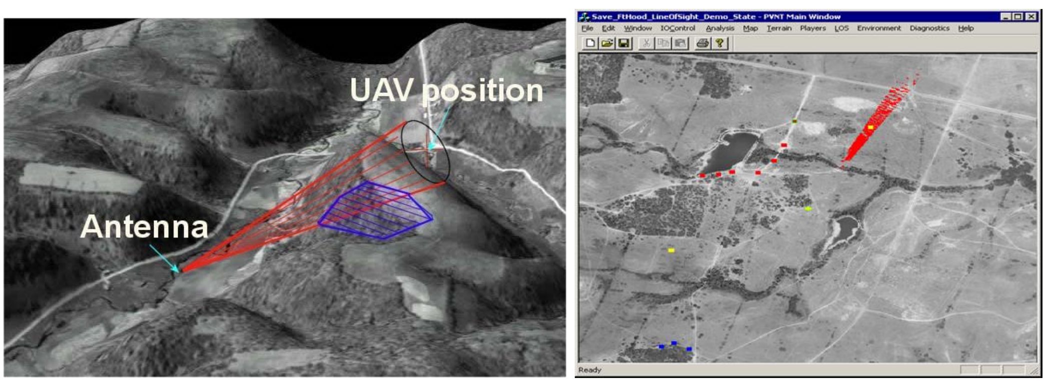

Figure 46. Envisioned Display of the Signal & Network Attenuation Prediction System

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VI. OUTLOOK AND RECOMMENDATIONS

A. APPLICATIONS, FUTURE DEVELOPMENT, AND MOBILITY

The ability to track and connect to a highly mobile node opens many new applications that are today constrained by the weak omni-directional connection. An example for a reasonable future application could be SPAWAR's URBOT. The robot could be controlled through the UAV network node. The reach would be significantly enlarged. Multiple applications in the military field immediately come to mind, but are not limited to this particular field. Homeland security and border control are additional fields were surveillance is key. Either the highly mobile UAV or the more static but ubiquitous balloon could be used to cover large areas with a wireless network.

The fact that the K2 system as it is today is limited to the support from the Sierra Nevada Corporation should be pressure enough to strive for independence. Further innovation should be the goal for future developments and therefore the independent development of a tracking unit is strongly recommended. The future system should have antenna mobility considered as an integral part from the start. Mobility here means compensation of platform movements (pitch and roll) as well as compensation of changing course and speed.

Miniaturizing and building a lightweight version of the payload for the UAV would allow for the employment of lighter and smaller UAVs, which therefore could be much cheaper and more expendable than the TERN. A symbiotic knowledge exchange between Dr. Kevin Jones, Naval Postgraduate School and the author allowed the development of a lightweight version with the same functionality as Generation 2 (no video feed). As of today, Generation 4 seems to become operational in August 2004 with a total weight of 570g excluding the battery pack.

Figure 47. Generation 4 Light Weight Network Payload

B. LINK MODELING

A system that would deliver real-time link modeling and simulation, considering terrain contours, LOS, atmospheric influence (refraction, absorption), and the mobility of the airborne network node is wishful thinking. A possible start for research could be to develop a method that uses the physical antenna in combination with a virtual UAV, which itself could be modeled and simulated with software. This would eliminate the variables that come with any UAV, which are low availability at relatively high cost. The envisioned simulation could deliver location and terrain profile data while employing link budget software to evaluate the link quality and range.

C. EXTRO

The concept of putting an 802.11b infrastructure node on board of an unmanned aerial vehicle proves to be valid and is very promising for future experimentation. Also, the evolutionary development of prototypes of payloads revealed many insights on the management side of the UAV/Network symbiosis.

The methodology of undertaking lab testing first and then bringing a fine tuned, more mature system to the field experiments appears to be an absolute must for implementing cutting edge COTS technology.

Many other facets of the specific research area Network/UAV which could not be covered in this thesis hopefully finds consideration in future graduate thesis work at the Naval Postgraduate School.

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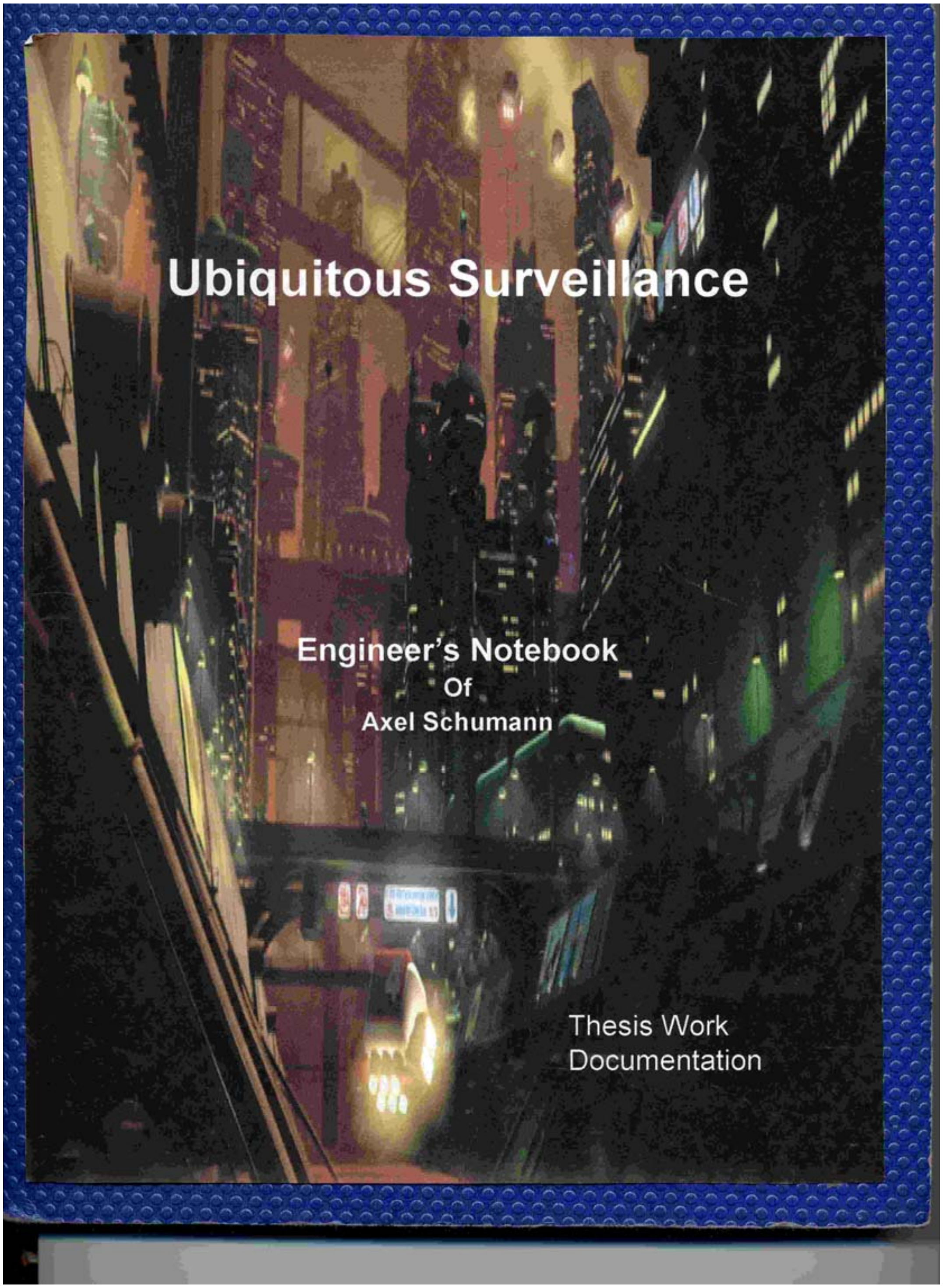
APPENDIX

A. ENGINEER'S NOTEBOOK



STAN 5 – First Steps in long-range networking

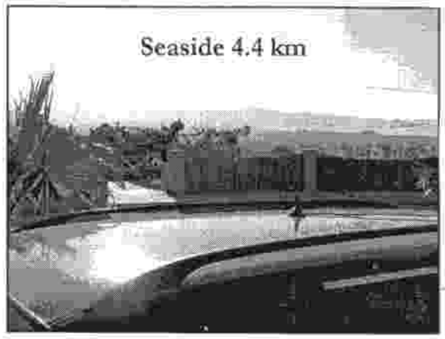
mobile NOC

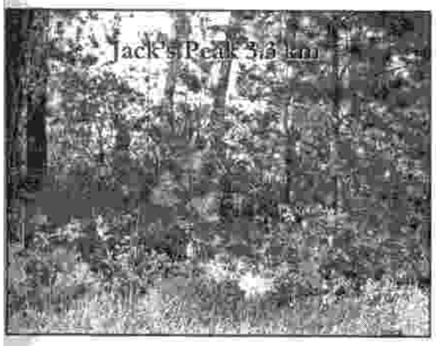
~~3800~~
~~4108.99~~
~~3000.99~~

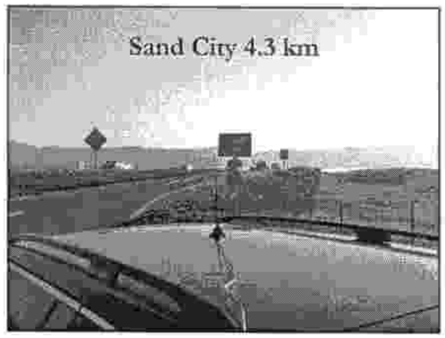
~~$741~~
~~$148 – ~$600~~

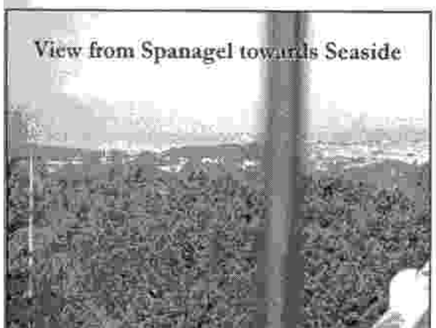
Cisco YAGI (14.5 dBi)
pointing at the Balloon
2 clicks (km) away.

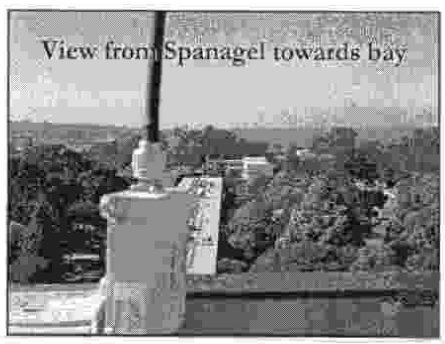
LONG RANGE NETWORKING FIELD TEST I 16.03.2004



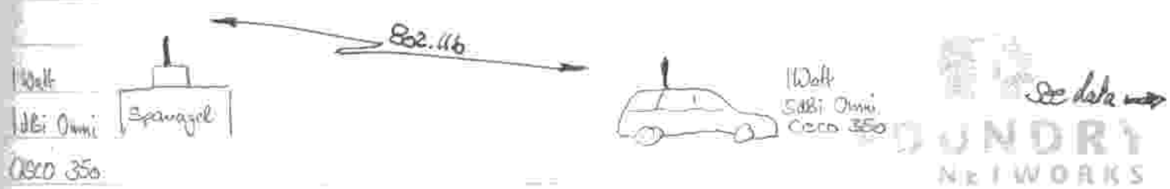








Network MAP:



DATA Field Test I :

- mobility possible
- good ranges for ARIES

Distance [m]	Elevation [m]	line of sight	avg. latency w/o load [ms]	avg. latency w/ load [ms]	link quality [kbps]
600	6	no	unknown	unknown	> 1000
1200	30	trees	unknown	unknown	> 1000
3400	190	yes	unknown	unknown	1000
3500	260	trees	unknown	unknown	1000
3400	300	trees	30	unknown	1000
4400	100	yes	24	630	730
4300	30	yes	35	559	300
4300 - 100	30 - 10	yes	300	unknown	> 300

Field Test II

- 3 Bridges
  - Root Bridge on Root Hall – 100mW - LOS
  - Non Root on Spanagel Hall – 1W - LOS
  - Non Root on Hermann Hall – 100mW – LOS to Sp
- Forced Connection via Spanagel by non-LOS to Root

Summary Field Test II

- → good connectivity
- Speed max. ~1.6 Mbps
- Seems that bandwidth is cut in half with each hop
- Spanagel max. 3.2Mbps
- Hermann max. 1.6Mbps

Screenshot from [illegible]

The Network Operations Center

Software: * What's Up Gold

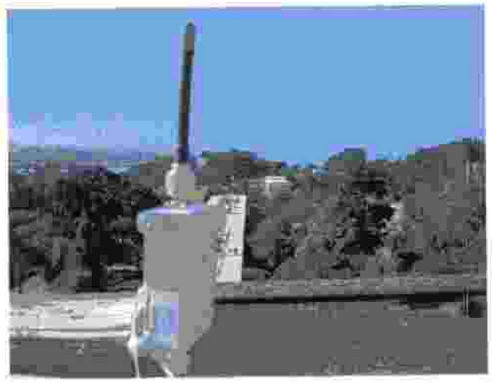
* Solarwinds Orion

* MRTG / PRTG

ARIES FIELD TEST

30 03 04

Root (AUV-3) 192 168. 4. 203   Toughbook 192.168. 4. 250



Balloon 192.168. 4. 206

ARIES (AUV-5) 192.168. 4. 205
NOCLAPTOP 192 168. 4. 222
Tablet 192. 168 4 207

non-root w/o clients
Balloon
.206

Tow non-root bridge w/o clients
.202

(Root)
Command Post
.203

Laptop .210
Toughbook .250

Aries non-root bridge w/o clients
.205

LAN

Tablet
.207

5db. MaxRad 1W ⟷ 5db 100mW Bridge Aries Camp Roberts

Distance	Bearing	Ack	Connectivity	Latency w/o load	Latency w/load
850 m	120°		✓ ✓	~5ms	
1275 m	120°		– ✓ –✓	~6ms	25.5MB – 8min 45s
1075 m	120°	900ft	✓ ✓	733kbps ~4ms	25.5MB – 4min 38s
2700 m	120°	920ft	✓	~6ms	no copy possible
2450 m	120°	940ft	✓	723kbps ~5ms	25.5MB – 4min 42s
3150 m	120°	965	– ✓	407kbps ~10ms	2.8MB – 55s
3.666 m	120°	970	– ✓	586kbps	953kB – 13s
2.700 m	055°	1170	✓	632kbps ~50ms	25.5MB – 5min 23s
~~2.950 m~~	~~055°~~			1062kbps	25.5MB – 3min 12s
2950 m	055°			~	
3.275 m	060°	1360	✓	~2ms	25.5MB – 6m 25s
2.500 m		1800 ⊕	✓	1387kbps	25.5MB – 2min 27s

1st Generation Payload Field Test

K2 Configuration + Integration

This is a fully functional K2 tracker unit with the normal Camp Roberts software load.

Bridge IP address: 192.168.1.76
GPS IP address: 192.168.1.31

Connect the power cable to +24 volts DC (red to "+", black to "-"). It should draw ~1.2 amps.

The tracker's status is available by web browsing to the GPS address and clicking on the STATUS link. The status web page is very wide; be sure to re-size the browser window or else you'll get a lot of line wraps.

After aligning the antenna positioner, the tracker will start in GPS_READ mode, waiting for its GPS antenna to acquire the GPS signal. If you remain indoors, the unit will forever wait in GPS_READ. It will output a GPS multicast on the network, but the location will be incorrect or may be zeros.
When you take the K2 outside the GPS will acquire and the K2 will start outputting a valid GPS multicast message. The GPS status is shown on the status web page, under the LCL GPS heading.

Once the GPS has acquir[...] to ACQUISITION mode an[...] message from the aircraf[...] RACK mode and start pointing a[...]

The unit is currently con[...] unit so that the initial power-up [...] rs and handle pointing south).

The IP address of the airc[...] may be changed by editing the fi[...] sed through FTP at the addre[...] for windows command line: [...] DR to the appropriate value. B[...]

The heading may be char[...] t currently is set to 0.0; It[...]

If you have any question[...]

Jack Cross
775-331-0222 work
775-233-1871 cell

Multicast GPS Data

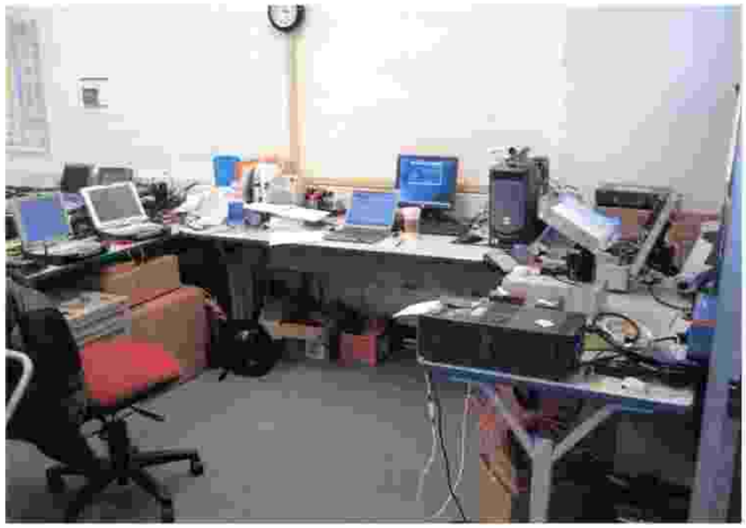
Each multicast player will
position at a nominal 1 hz
input it has to derive the
just multicast a fixed mes:

Each player must multicast
information is maintained.
carriage return/line feed,
specification.

The position will be multic
means 'all systems on this
that it is possible to char
any conflicts in addressinç

Any client that is interest
updates.

The sender sends a packet c
separated by cr\lf. Some ir
needed data. The data is al
webpages.com/peter/nmeafaq.



Identification of nodes on the network is done by IP address. The receiver must look at the socket level information to get the IP address of who sent a particular message. I.e. use 'recvfrom'. A separate listing that provides the mapping of IP address to node name will be compiled for each experiment.

Example message
```
$GPGGA,123519,4807.038,N,01131.324,E,1,08,0.9,545.4,M,46.9,M,,*42<cr><lf>
$GPRMC,225446,A,4916.45,N,12311.12,W,000.5,054.7,191194,020.3,E*68
```

Message Reference:

```
        GGA - Global Positioning System Fix Data
        GGA,123519,4807.038,N,01131.324,E,1,08,0.9,545.4,M,46.9,M, , *42
           123519       Fix taken at 12:35:19 UTC
           4807.038,N   Latitude 48 deg 07.038' N
           01131.324,E  Longitude 11 deg 31.324' E
           1            Fix quality: 0 = invalid
                                     1 = GPS fix
                                     2 = DGPS fix
           08           Number of satellites being tracked
           0.9          Horizontal dilution of position
           545.4,M      Altitude, Metres, above mean sea level
           46.9,M       Height of geoid (mean sea level) above WGS84
                        ellipsoid
           (empty field) time in seconds since last DGPS update
           (empty field) DGPS station ID number


        RMC - Recommended minimum specific GPS/Transit data
        RMC,225446,A,4916.45,N,12311.12,W,000.5,054.7,191194,020.3,E*68
           225446       Time of fix 22:54:46 UTC
           A            Navigation receiver warning A = OK, V = warning
           4916.45,N    Latitude 49 deg. 16.45 min North
           12311.12,W   Longitude 123 deg. 11.12 min West
           000.5        Speed over ground, Knots
           054.7        Course Made Good, True
           191194       Date of fix  19 November 1994
           020.3,E      Magnetic variation 20.3 deg East
           *68          mandatory checksum
```

The checksum field consists of a "*" and two hex digits representing the exclusive OR of all characters between, but not including, the "$" and "*".

AIRTRAC 1 k2 Configuration 06.04.2004

Bridge: 192.168.1.72
GPS: 192.168.1.34

changes: power 5W disconnected
disable radio / change to left antenna
change output power 100mW
SSID: Stau Role. Root.

TactiComp

192.168.1.239 GPS working

GPS Config: TGU.CFG

SNC_WEB = 0.0.0.0:80
ACGPS_ADDR = 192.168.1.37:0
PTU_BAUD = 9600
PTU_PORT = /tyCo/1
LCL_GPS_BAUD = 4800
LCL_GPS_PORT = /tyCo/2

k2

multicast Syntax: mserver -f "C:\...\RTCLog.txt"

775-331-0222 Jack Gross 14.04.03 k2 resolving

- Heading true north
- data: tgu.cfg (no)

→ heading.txt hdg. 205 → change 0

changed value in "Heading.txt" to "0.0"

→ k2 AirTrac1 k2 works + tracs

STAN 6 Recommendation for

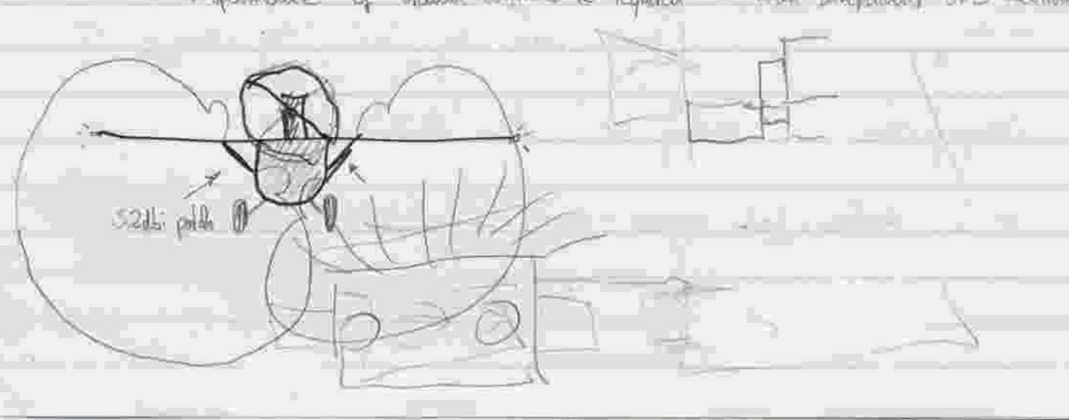
AirBorne Nodes 15.04.2004

Amp ~30
350 12
5

Balloon: 2 Bridges 2*5Watt Amp. (separation !
1 directional antenna 16s
1 omni rubber-duck
2·(40W → Batteries)

TERN: • 1 Bridge • 1*2 Watt Amp. 180 70?? (~1300,-)
• Shut down switch (low voltage)
• 1 Rubber-duck antenna (omni) ~~on tail~~
• 1 directional antenna → What do we have??
• 1 by 2 splitter (resistive)
* interchanging use of antennas
∘ patch ∘ omni 18dBi ∘ omni 2.3 dBi

K2: • 1 ~~is working~~ → dying, other has cover.
• GPS data stream?
Who knows?
• VCG TERN GPS not accessible
• Independence of Ground Control is required → build independent GPS solution

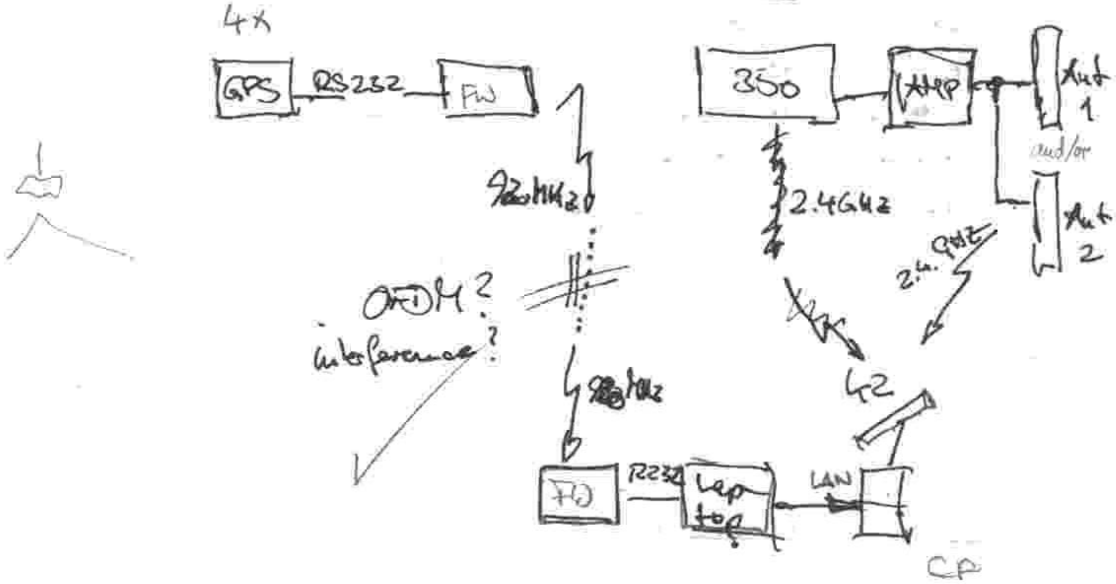


10th

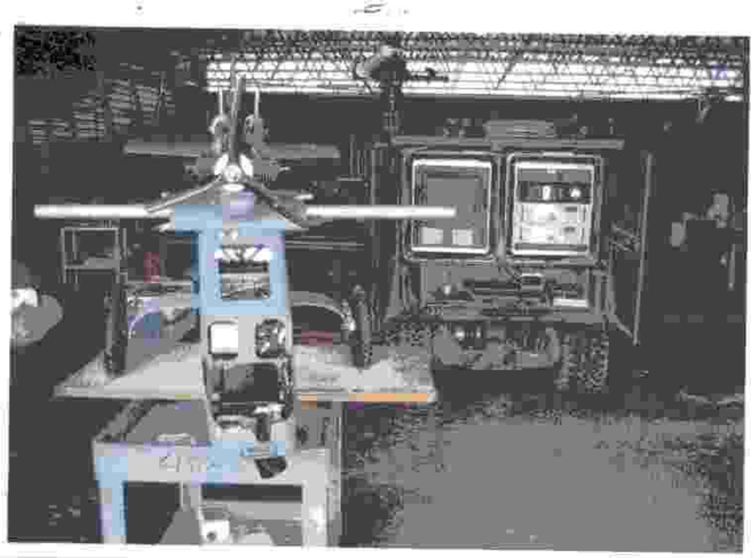
30.04. – 05.05. – 12.05.

STAND 6

802.11 Independent GPS Implementation Architecture

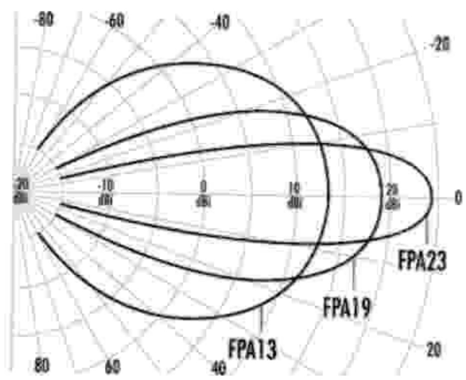


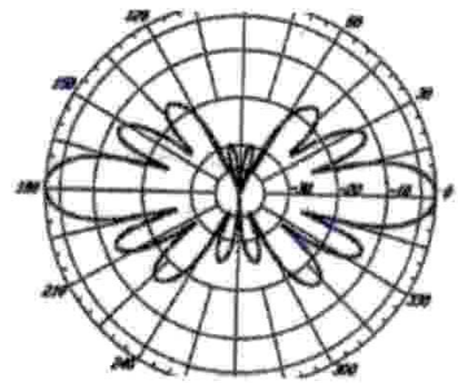
Order: Antennas: Patch 360° Cisco



Camp Lejeune

01.06. travel
2+3. setup
4.+5. initial testing
6.-9. operation
10+11. clean up
12.06. travel back





Support for JCTFEX 2004
Joint Command Task Force Exercise

Camp Roberts Travel + Experiment

02.05. Sunday CR

CODE: RHE34

Comfort Suites Jacksonville NC 28546
HW 17N, 130 Workshop Lane
910-346-8900
800-228-5150

Battery Pack k2 16.04.2004

1 battery : 24 cm × 12,5 cm

k2:

24V @ 1.2A

$P = U \cdot I$

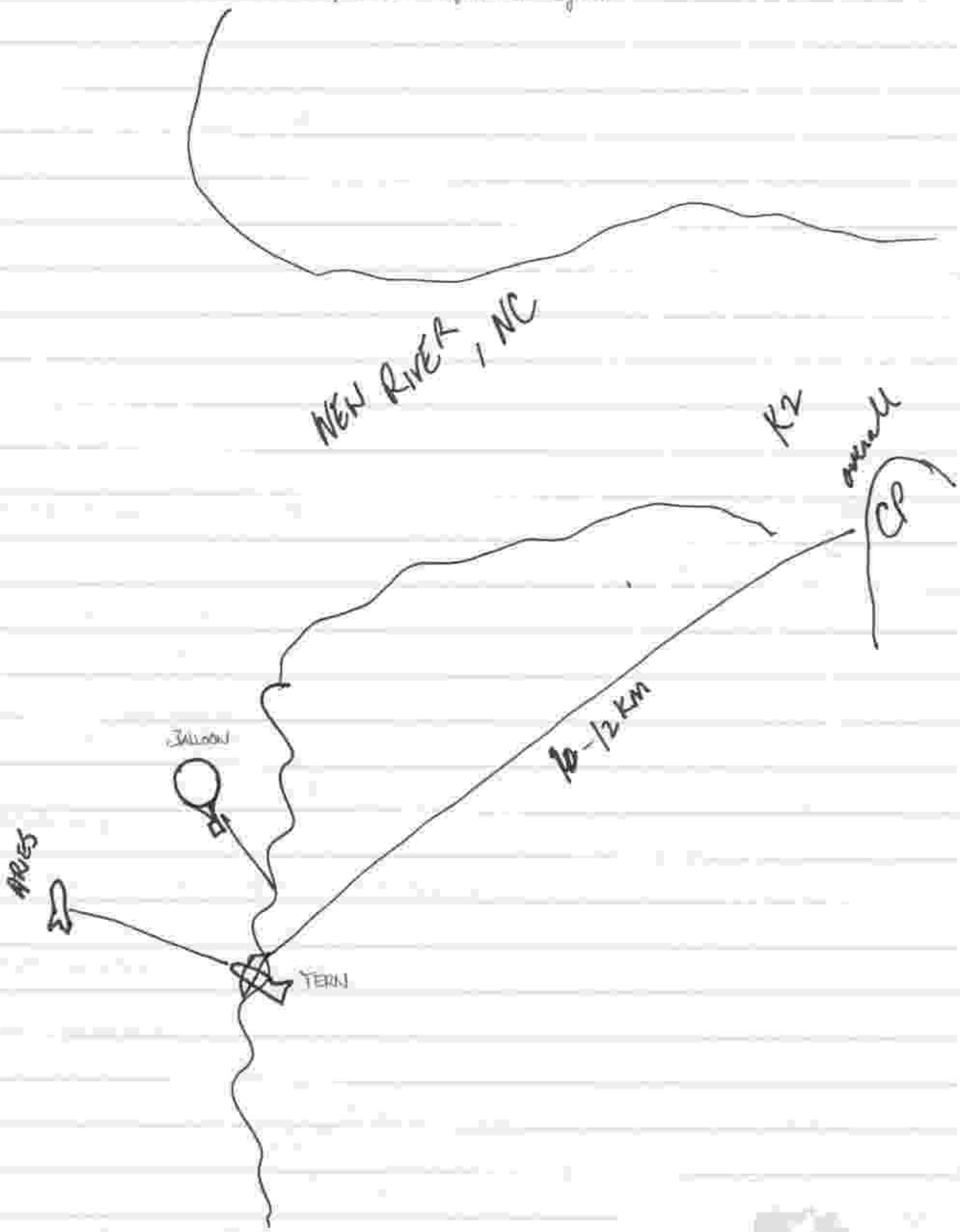
$= 24 \cdot 1.2\ [W]$

$P = 28{,}8\,W$

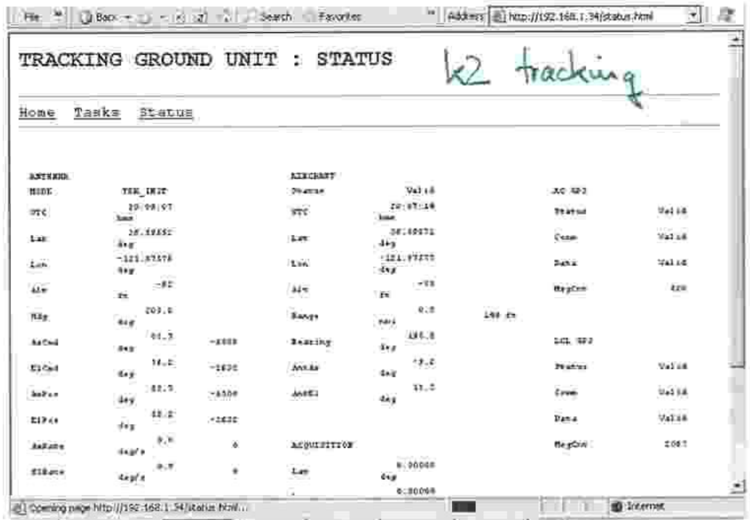
each batterie 45Ah / 12V @ 1.2A => 37.5h of operational time

Camp Lejeune NC

possible experiment layout



k2 test plan 19.04.04


TRACKING GROUND UNIT : STATUS

Home Tasks Status

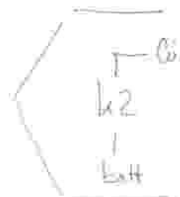
ANTENNA

MODE	TRK_INIT		AIRCRAFT Status	Valid		AC GPS	
UTC	20:08:07 hms		UTC	20:07:18 hms		Status	Valid
Lat	38.39351 deg		Lat	38.38871 deg		Comm	Valid
Lon	-121.87378 deg		Lon	-121.87377 deg		Data	Valid
Alt	-82 ft		Alt	-73 ft		MsgCnt	420
Hdg	203.0 deg		Range	0.0 nmi	188 ft		
AzCmd	61.3 deg	-2000	Bearing	186.8 deg		LCL GPS	
ElCmd	16.0 deg	-1620	AntAz	-7.2 deg		Status	Valid
AzPos	62.5 deg	-2500	AntEl	31.0 deg		Comm	Valid
ElPos	12.2 deg	-1620				Data	Valid
AzRate	0.0 deg/s	0	ACQUISITION			MsgCnt	2087
ElRate	0.0 deg/s	0	Lat	0.00000 deg			
				0.00000			

Opening page http://192.168.1.34/status.html...

k2 tracking

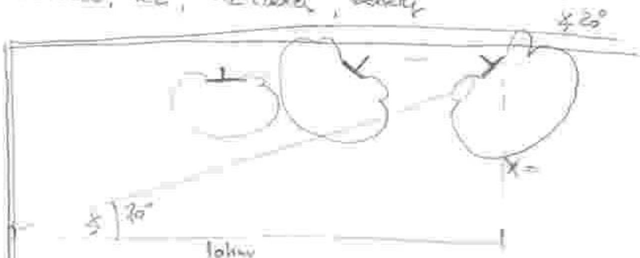
1230 - 1300 get cable fixed setup



→ prep. · setup :
· fix cable ...
· send email to Vlad ✓
· prob. antenna, Circo ✓, Screwdriver ✓, Styles ✓
TB-2 ✓, GPS ✓, Serial cable ✓, k2 ✓, k2 cover ✓, battery ✓

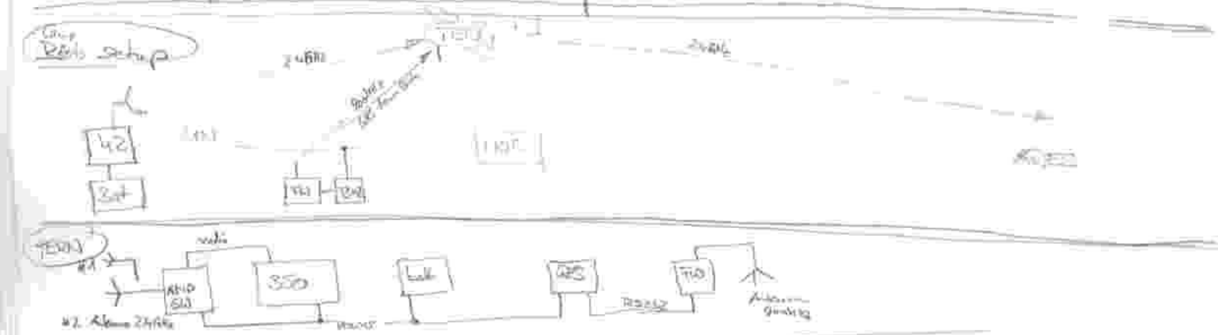
1315 · Boot k2 ✓
· verify server + bridge is up ✓
· GPS up? ✓ ~2 min
· move to other location
· get GPS AC up ✓
· feed GPS in network ✓
· k2 lock on? ✓
· see screenshot k2_working-2
· compare to k2_working

1400 · complete



develop procedure to calculate flight level vs. distance

see next page



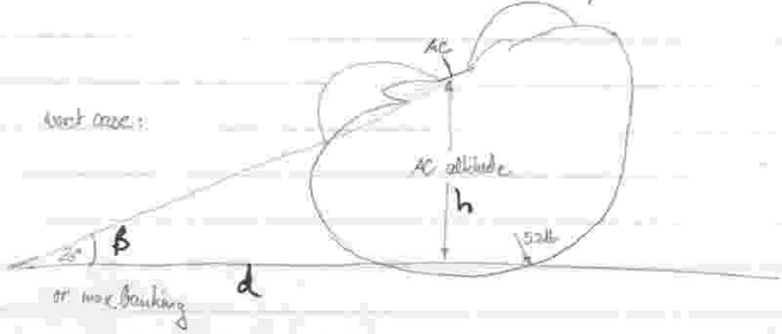
20.04.04 Coverage investigation

Flight level versus distance for optimal coverage

Assumptions: * average AC banking 20°
* used antenna OSSO 6dBi patch mounted on bottom of AC

$$\tan(\beta) = \frac{h}{d}$$

$$h = \tan(\beta) \cdot d$$



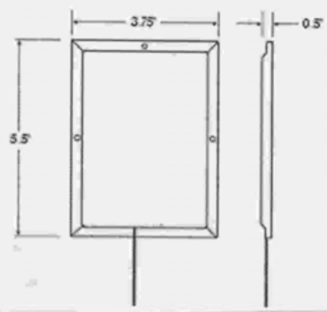
Dependence of the distance and altitude vs. banking angle for max. pattern coverage					
max. AC banking [deg]	10	20	30	40	50
Distance [km]	min. Altitude [m]	min. Altitude [m]	min. Altitude [m]	min. Altitude [m]	min. Altitude [m]
1	176	364	577	839	1192
2	353	728	1155	1678	2383
3	529	1092	1732	2517	3575
4	705	1456	2309	3356	4767
5	882	1820	2887	4195	5958
6	1058	2184	3464	5034	7150
7	1234	2548	4041	5873	8342
8	1411	2912	4619	6713	9534
9	1587	3276	5196	7552	10725
10	1763	3640	5773	8391	11917
11	1940	4004	6351	9230	13109
12	2116	4368	6928	10069	14300
13	2292	4731	7505	10908	15492
14	2469	5095	8083	11747	16684
15	2645	5459	8660	12586	17875

Doc: UAV_distance_vs_altitude.xls

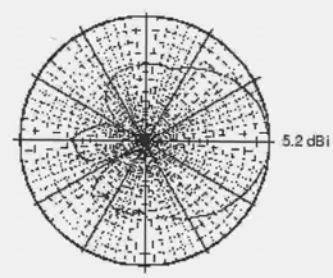
kan: find out operational data of UAV (Banking angle vs. radius)

6dBi Patch AIR-ANT 1729

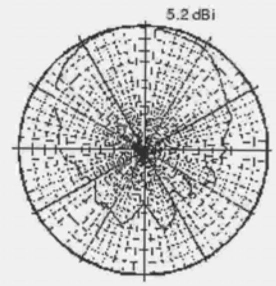
Dimensions and Mounting Specifications



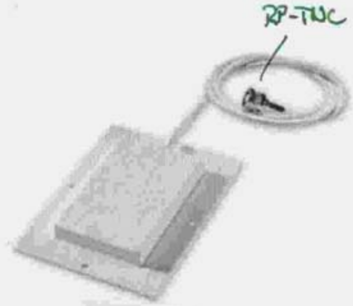
Vertical Radiation



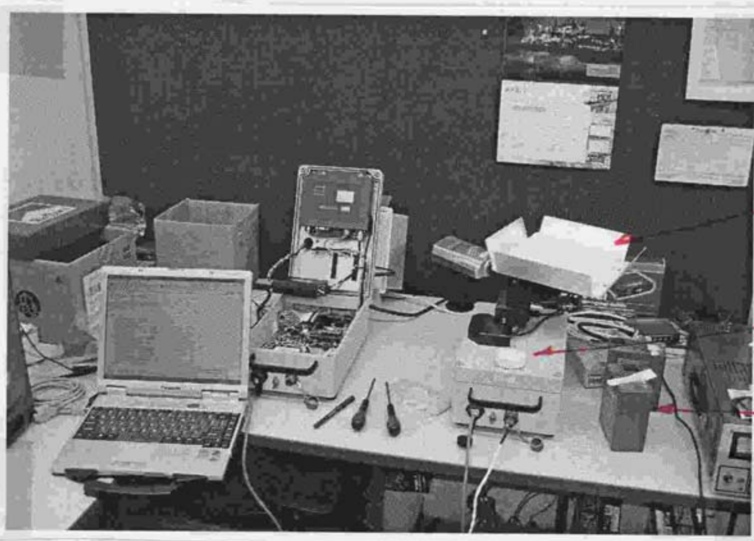
Horizontal Radiation



from cisco antenna tutorial

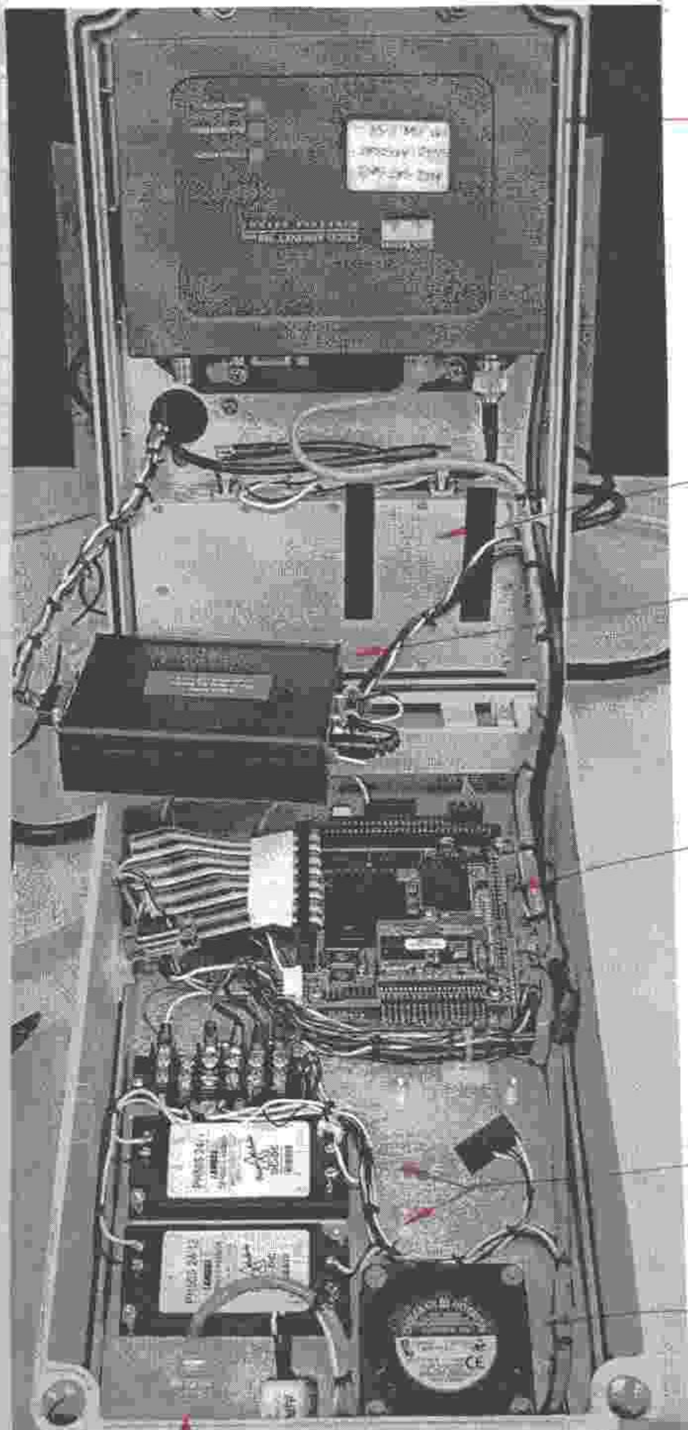


Frequency: 2.4 - 2.5GHz
VSWR: Less than 2:1
Gain: 5.2 dBi
Polarization: Linear
Azimuth 3dB: 65°
Elevation 3dB: 70°



14.5 dBi patch (±15° Beamwidth)
GPS receiver + antenna
24V batterie

k2 inside-out



Cisco 350 bridge

5W 2.4GHz amplifier

pan-tilt controller (RS232)

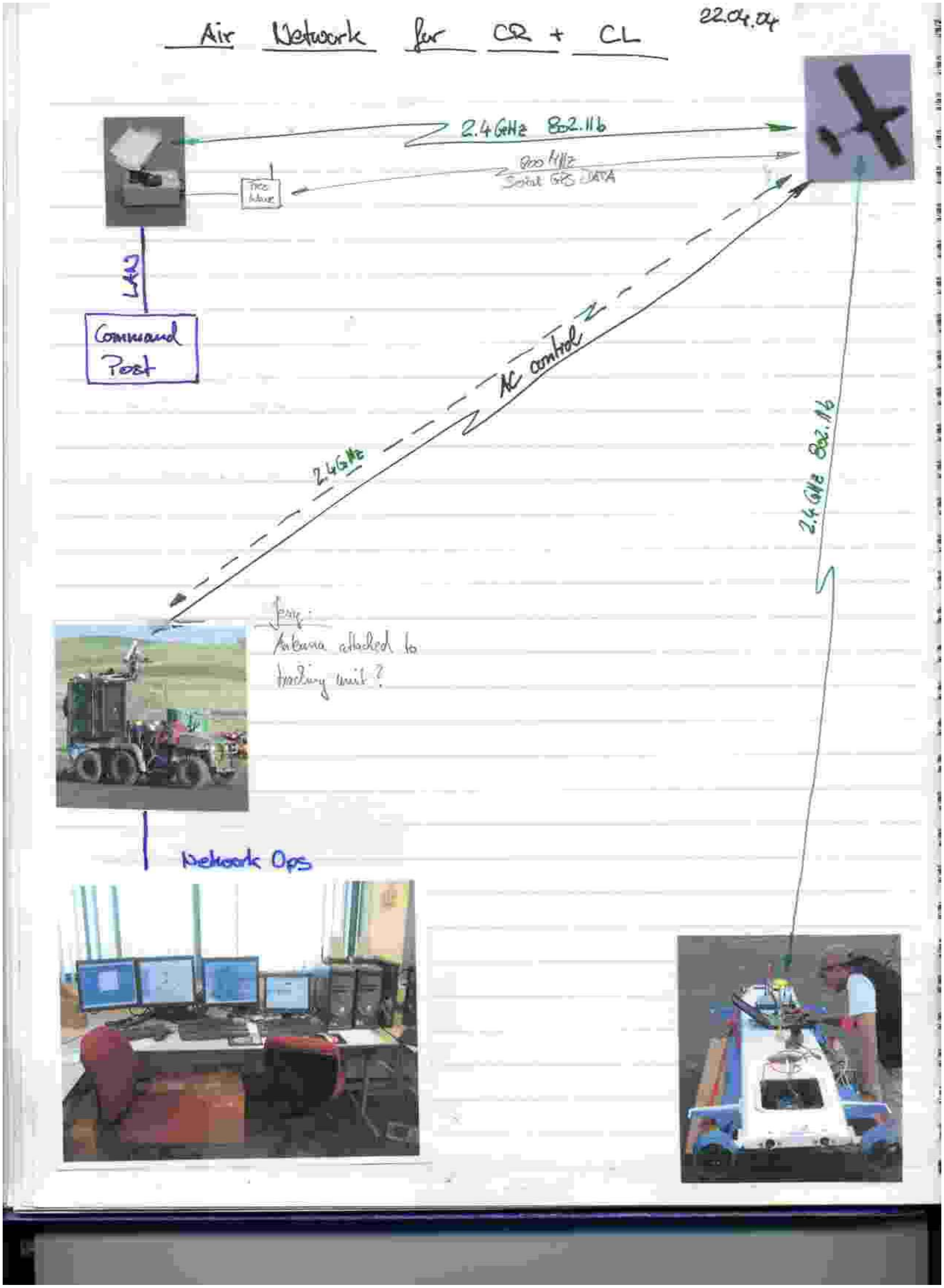
PC 104 (with NIC)

DC-DC converter

fan

LAN RJ45

POWER 24V


Air Network for CR + CL
22.04.04
2.4 GHz 802.11b
900 MHz
Serial GPS DATA
LAN
Command Post
AC control
2.4 GHz
2.4 GHz 802.11b
Antenna attached to tracking unit?
Network Ops

Axel Schumann | DEU

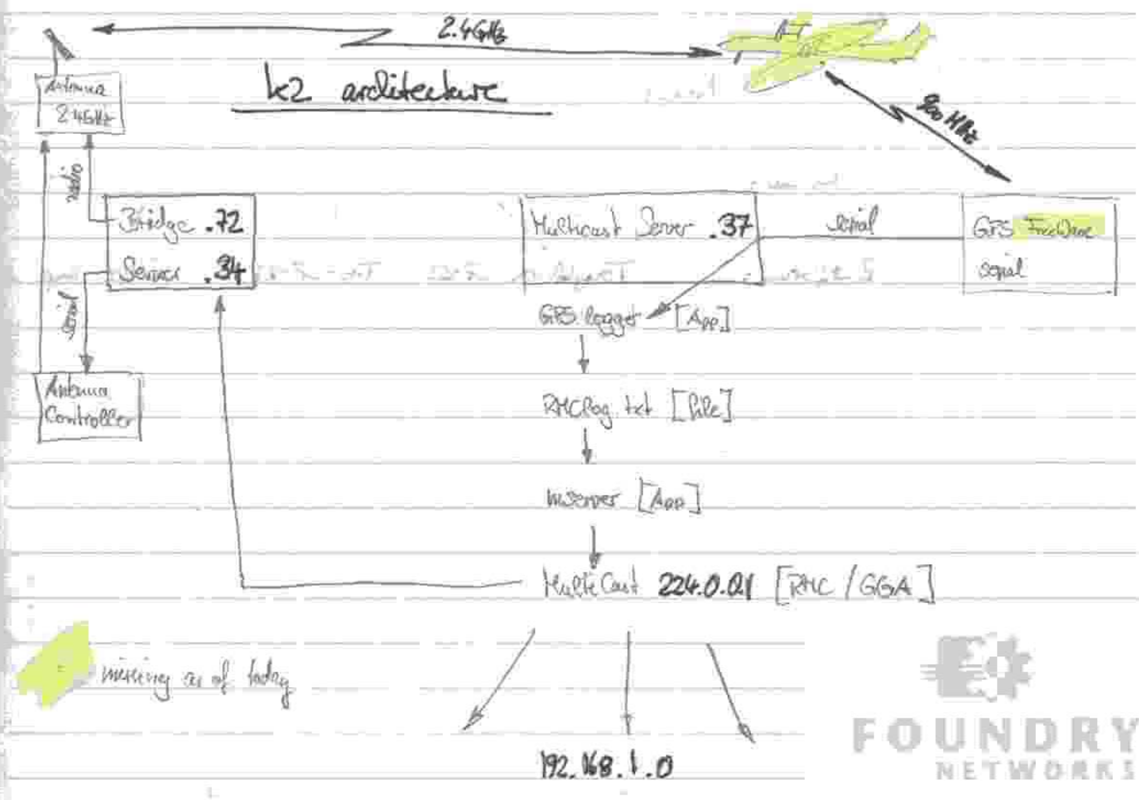
From:	Healey, Tony USA [healey@nps.edu]
Sent:	Thursday, April 22, 2004 12:35 PM
To:	Lentz, Jerry USA; Schumann, Axel DEU; Jones, Keith USA; Jones, Kevin; Horner, Doug USA; Dobrokhodov, Vladimir RUS Contractor ; Netzer, Dave USA; Kaminer, Isaac USA
Subject:	RE: Bridges and Amps

The 2.4 GHz. freewave radios cannot be used for the GPS transmissions. We always intended for the 960MHz. serial comms based radios to be used. It looks like we may need to have a details meeting this afternoon.

Lets meet per Dave Netzer's earlier mail to discuss all concerns. Plan to stay a little late if necessary.

Tony
My issues:

1. Status of Balloon package for CR and CL
2. Status of SOCOM TERN for CR and CL
3. Status of K2 for CR and CL
4. Status of ARIES for CR and CL
5. Transportation Issues?



22.04.04

STAN 6 PLANS

- Sunday VCB operable
- Security on all Bridges
- Talk to VCG

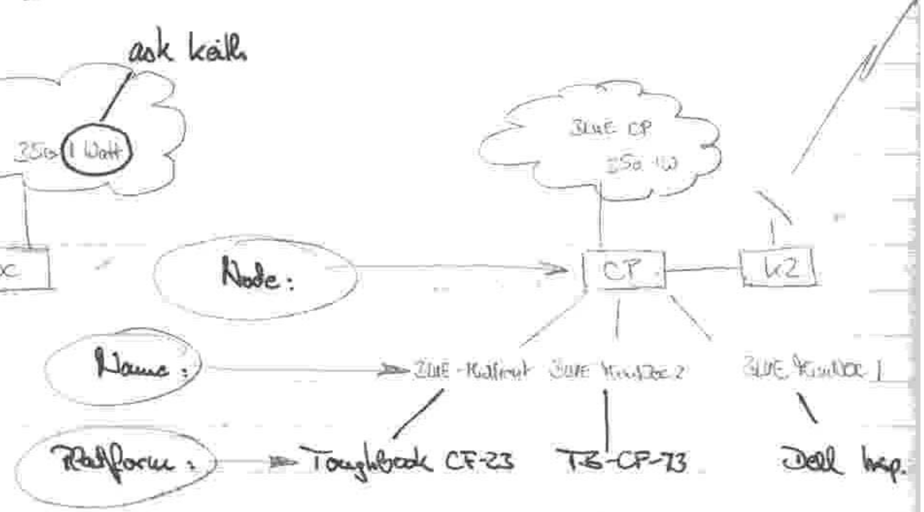
Interference Runway Tests

SSID: no broadcast stanAIR
key: RBM=shared AFA1234567890AFA1234567890 (26 dig Hex
Login: blue PW: blue
SNMP: anon

(specialised PPD data, Antenna)

WEP: shared → open (more secure)

Producer
Solarwinds ✓
Q-Check ✓
mscrver



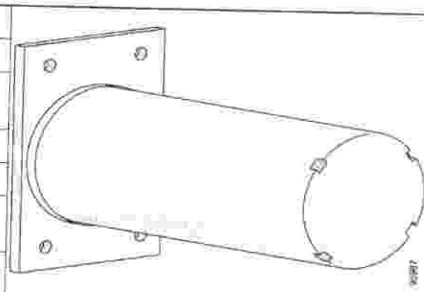
keith: magnetic mount + 5dBi MaxRad Antenna
pic tail

Cisco 10dBi Yagi Antenna
as option for the ground control station

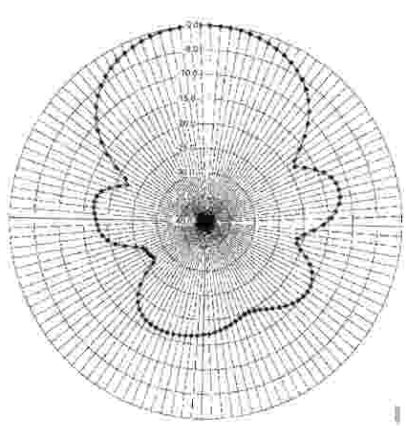
26.04 2004

Technical Specifications

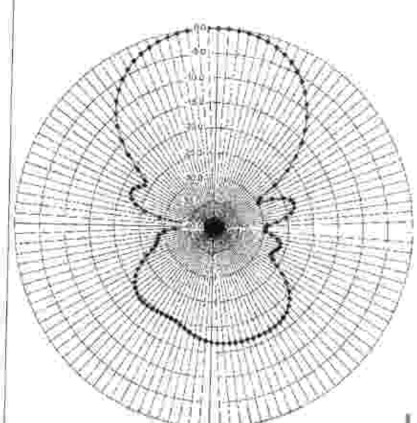
Antenna type	Yagi
Operating frequency range	2.4 to 2.83 GHz
VSWR	Less than 2:1, typically 1.5:1
Gain	10 dBi
Polarization	Vertical
Front-to-back ratio	Greater than 13.5 dB
Horizontal half-power beamwidth	47°
Vertical half-power beamwidth	55°
Length	7.25 in. (18.4 cm)
Width	3.125 in. (7.9 cm)
Height	5 in. (12.7 cm)
Tube diameter	3 in. (7.6 cm)
Cable length and type	3 ft. (0.91 m) RG-58
Operating temperature	140° F to –40° F (60° C to –40° C)
Wind rating	120 MPH (193 KMPH)



Azimuth Radiation Pattern



Elevation Radiation Pattern

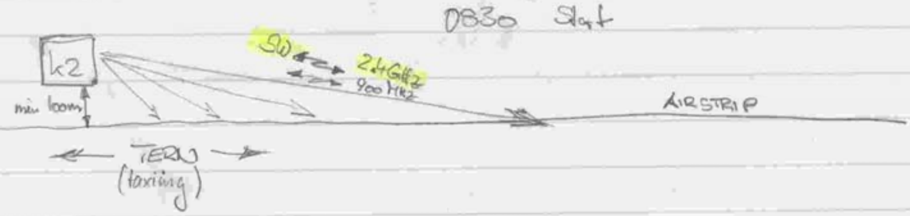


NETWORKS

SWAN 6 Test Plan EMI

Runway Interference Exclusion Testing:

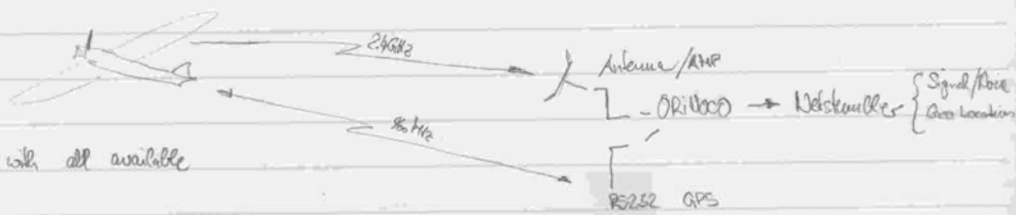
0730 Briefing
0800 Setup
0830 Start



open: find location for k2, → get Map

Signal Strength Measurement via k2 (TERN in the Air)

open: • split serial port → Netstumbler
• pigtail Orinoco → Netstumbler



Test Runs with all available Antennas

(EMI) testing on the runway, Camp Roberts 03.05.[illegible]

CISCO SETTINGS

K2: Root Bridge ; 50mW ; STP enabled

TERN: Repeater Access Point ; 100mW ; } Bal
Shup

NOC: Non-Root w/clients ; 1mW ;
no-STP

Balloon 1: Non-Root w/o - client no-STP

Balloon 2: Non-Root w/client no-STP

=> AIRBORNE NODE is always Root

=> enable STP to minimize Path + Redundancy

Security Implementation for STAN6

CISCO 350 bridges (Axel):

- Enable WEP; Key
- Suppress SSID broadcast:
- Enable login on all devices

Servers (NOC team):

- Disable all unused services, especially ftp-write
- Latest patches and updates

Clients / all machines (everybody):

- Disable workgroups
- Latest patches and updates
- Disable shares

Used key and SSIDs for STAN6:

- See your GigaLab representative
- (128bit, HEX): **AFA1234567890AFA1234567890**
- SSID: **stanNOC, stanAIR**

FOUNDRY NETWORKS

Camp Roberts 04.05.04 **TERN TRACK TEST**

Take off: 8:56 — 2.4 mw / 1500 agl

Landing: 9:30 — ~ 400 kbps

Solid tracking — no interference detected!

Connectivity aquired:

11:18 TERN → first_TERN_track.txt

11:21 ARIES

Long Range Log — 05.05.04

I: 1. 2.852 MB — 1:48 sec => 211 kbps

2: 2.852 MB — 1:28 sec => 259 kbps

3: 2.852 MB — 1:22 sec => 278 kbps

II: ~~1. 6317 MB~~ — ~~24~~ — 12:15

1: 953 kB — 31 sec => 245 kbps

2: 953 kB — 30 sec => 254 kbps

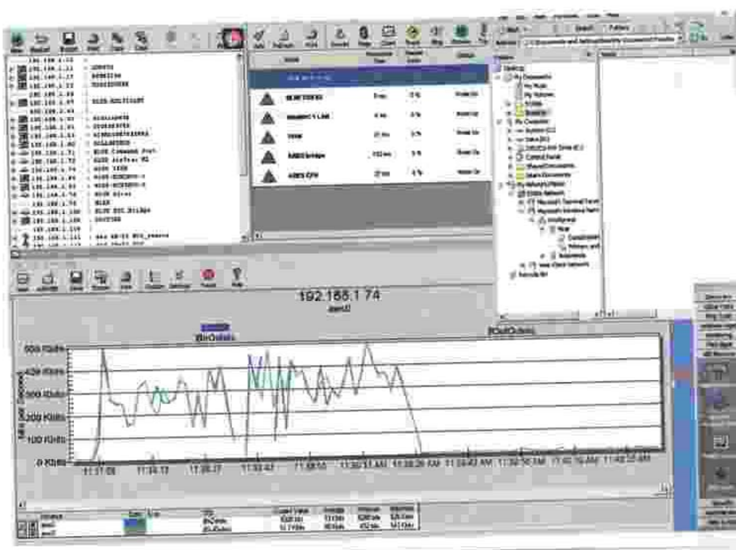
3: 953 kB — 36 sec => 211 kbps

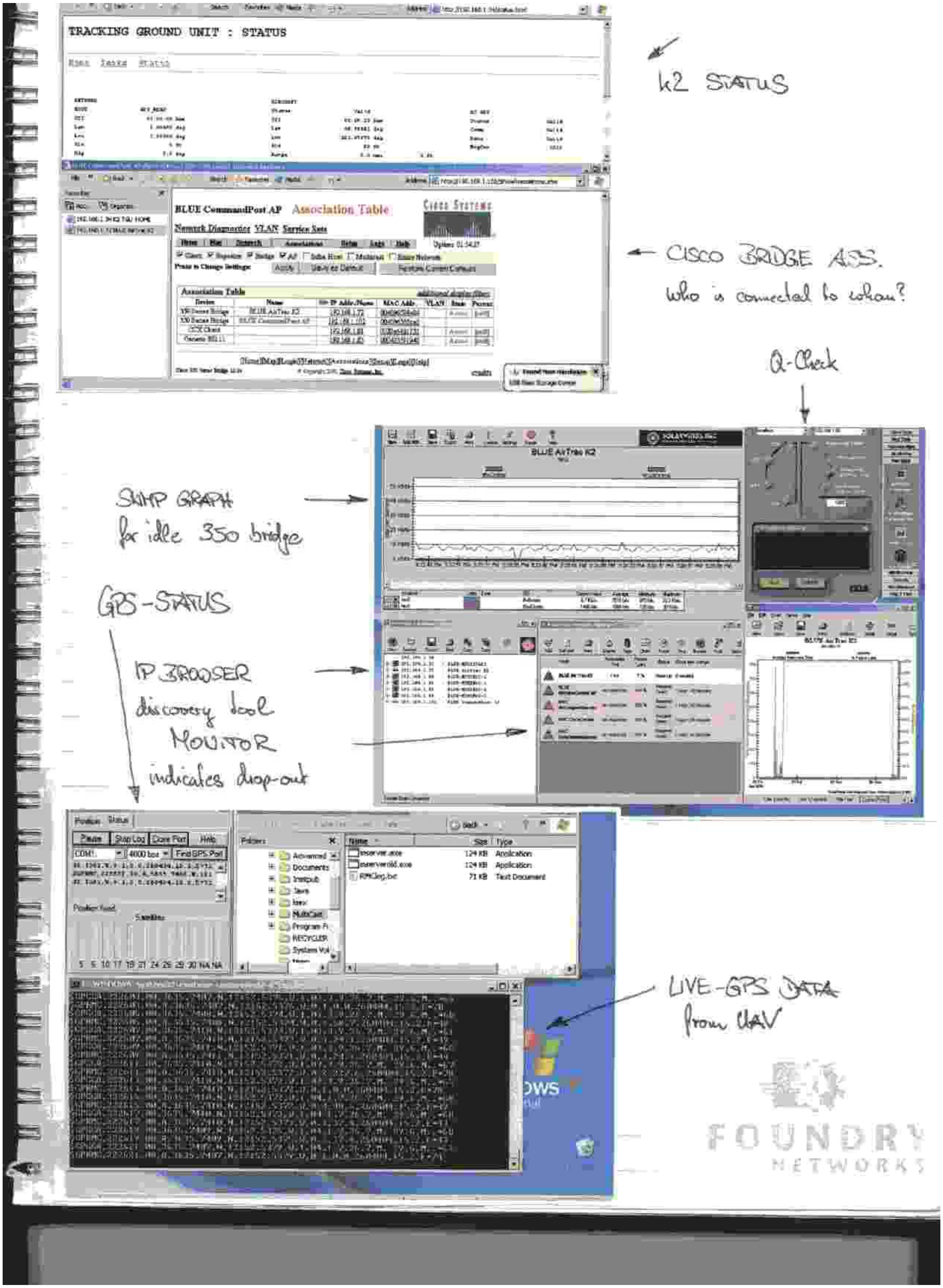
III: 1. 6317 kB

lost connectivit

→ most probab

→ get stuc




TRACKING GROUND UNIT : STATUS
k2 STATUS
BLUE CommandPost AP Association Table
CISCO SYSTEMS
CISCO BRIDGE ASS.
who is connected to whom?
Q-Check
BLUE AirTrax K2
SNMP GRAPH
for idle 350 bridge
GPS-STATUS
IP BROWSER
discovery tool
MONITOR
indicates drop-out
LIVE-GPS DATA
from UAV
FOUNDRY
NETWORKS

05.05.2004

VC-6 TERN with operational payload

- top dipole antenna: 900MHz GPS data down link
- top patch antenna: GPS antenna
- bottom dipole antenna: 2.4GHz 802.11b network radio link

Checklist for Tern Bridge format

The tern has two antennas and a Cisco Bridge and 2 Watt amplifier in the nose. A power converter is just back of the nose bulkhead, and a Freewave transmitter and Garmin GPS is added Velcroed to the Gas tank. The GPS antenna is velcroed behind the antenna on the top of the nose which is the Freewave wireless modem for the GPS. The GPS is velcroed to the Freewave on the Gas tank.

1. Check that the switch for the bridge and GPS system is turned on before flight by pushing the switch (Under the lipstick camera on the side) FORWARD.
   a. Check with K2 operator to make sure GPS is received from the Bridge system before flight. The operator boots up the K2 and it will point to the plane.
2. Turn off the switch by pushing it BACKWARD after the flight.

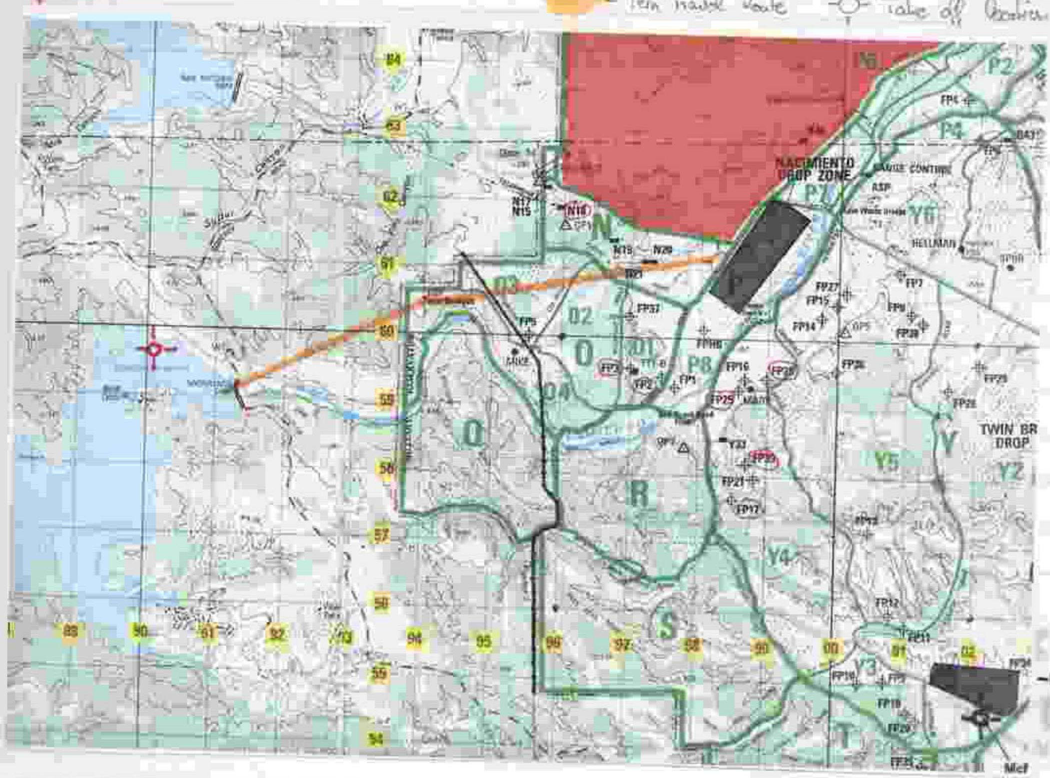
Pre-post flight Check

1. Make sure the battery (rechargeable) in the tail is velcroed in and plugged and has charge. There is a Liquid Crystal charge meter on the battery which should last 6 hours.
2. Make sure the freewave links to the TOC and K2. (Check with Axel)
3. Both the top antenna wire and the bottome antenna wire and the GPS must be properly connected.

LONG RANGE SETUP / LOCATIONS 05.05.04

ARIES

Tern Travel Route — Take off Location



Payload 2nd Generation

- CISCO 350
- 2W amplifierer
- 4 different antennas
  - 6dBi patch
  - 3 dBi omni dipole
  - 3 dBi thumb
  - 1 dBi omni

11.05.2004: How about tapping into the video?

- mount web cam? (digital)
- use lipstick? (analog)

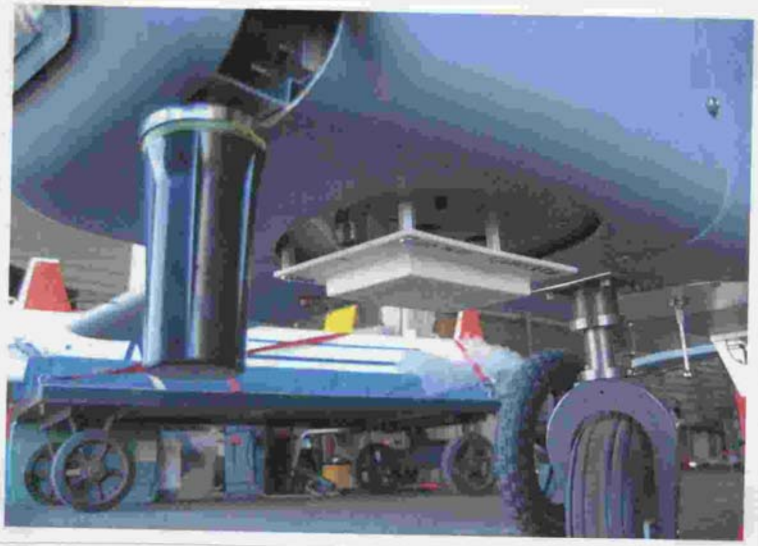
→ feed analog into network with PELCO

lipstick cameras

patch antenna

Batterie

03. May 04



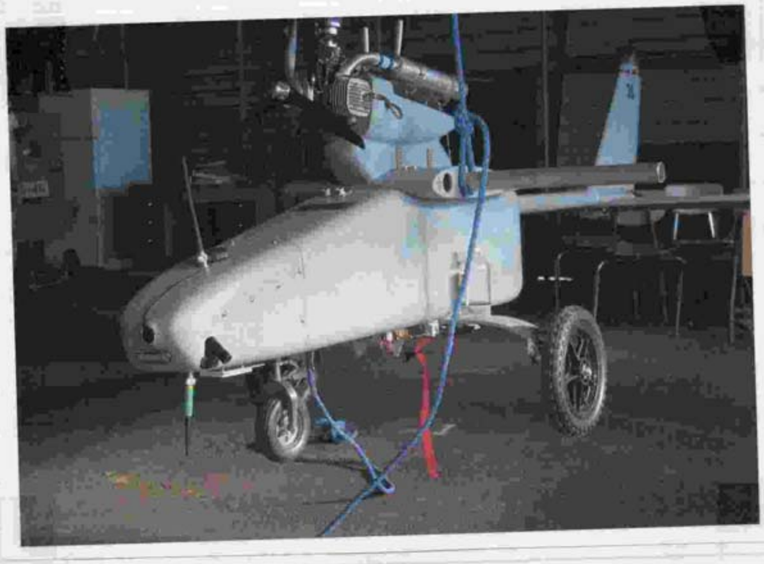
notice
ARIES in
background

barrel connector for alternative antenna (cone ?)

alternative 3 dBi dipole

FOR TERN (2nd G)

is Balanced (notice water Bottle!)



Ground Control Station (GCS) VC-6

upper window: fwd looking camera (approaching air strip)

Infrastructure vs. Adhoc ?

ARIES

Naval Postgraduate School 3.03.04

Monterey, California

Axel Schumann 162 Littlefield Road Monterey, CA 93940 Tel (831) 373 5239 ASchuman@nps.navy.mil

tentative outline :

Networking —

* Need for networking in Surveillance →
  - long range
  - wireless → airborne
* first approach
  - 3CO bridges infrastructure NW
* second approach
  - adhoc NW (w. mesh, pybuilt, mesh, ...)
* final working network / proof of concept

LAKE NACIMIENTO FIELD TEST

3-May

Lake Nascimiento - Where we have ARIES located in the water on the North side of the lake
The balloon was located on the top of the knoll at the entrance to the recreation area
the K2 was located with the ARIES.

ARIES position 897598
Balloon: 916585

Configuration: ARIES 2-3dbi antenna 75 degree upward looking with 1 watt amplifier
Balloon: 5 dbi antenna and 5 watt amplifier
CP: K2 5 watt amplifier 14.5 dbi directional antenna 200km

1

File Size (MB)	Time (sec)	Mbps
2.852	28	0.814857
2.852	25	0.91264
2.852	33	0.691394
6.317	123	0.410862
6.317	206	0.24532
6.317	141	0.358411
0.953	13	0.586462
0.953	20	0.3812
0.953	33	0.23103
0.953	21	0.363048

Note wind was picking up quite a bit possibly causing the K2 to have difficulty tracking the balloon

3-May

Height of the balloon is 560m
First location of the K2: LAT 35 44.652 LONG 120 57.827 at 7.47 km from the balloon package to the K2
ARIES Location: Same as day before at North access ramp

Successful link with the K2 at 1058 in 27ms (balloon to K2 in 8 ms)
Successful link with ARIES thru the balloon at 8ms (balloon to K2 improved to 4ms)
Little to no wind at 1100 permited the balloon to get fully vertical

2

File Size (MB)	Time (sec)	Mbps
2.852	64	0.3565
2.852	74	0.308324
2.852	81	0.281679

Time
1103 Starting from the Windows file sharin

Tried to set the maximum packet size (to 11MB) and the cisco bridge and it shut the system down
Originally it was set to a throughput of 1mbps
802.11B has three mbps throughput 1 5.5 and 11mbps

1205

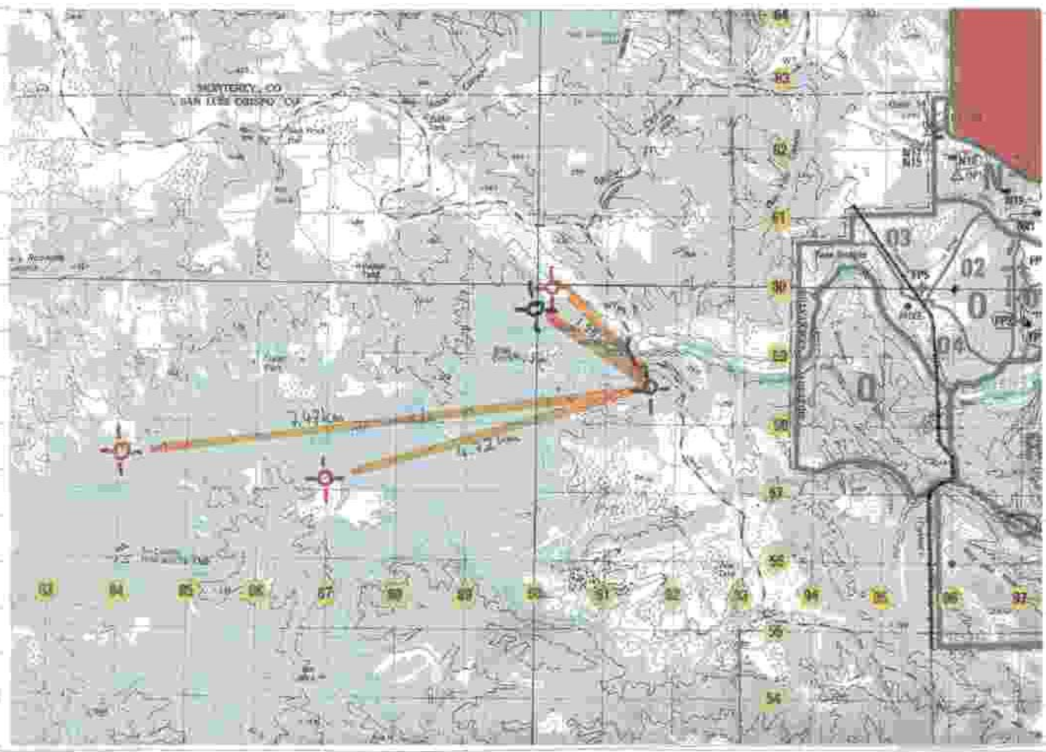
3

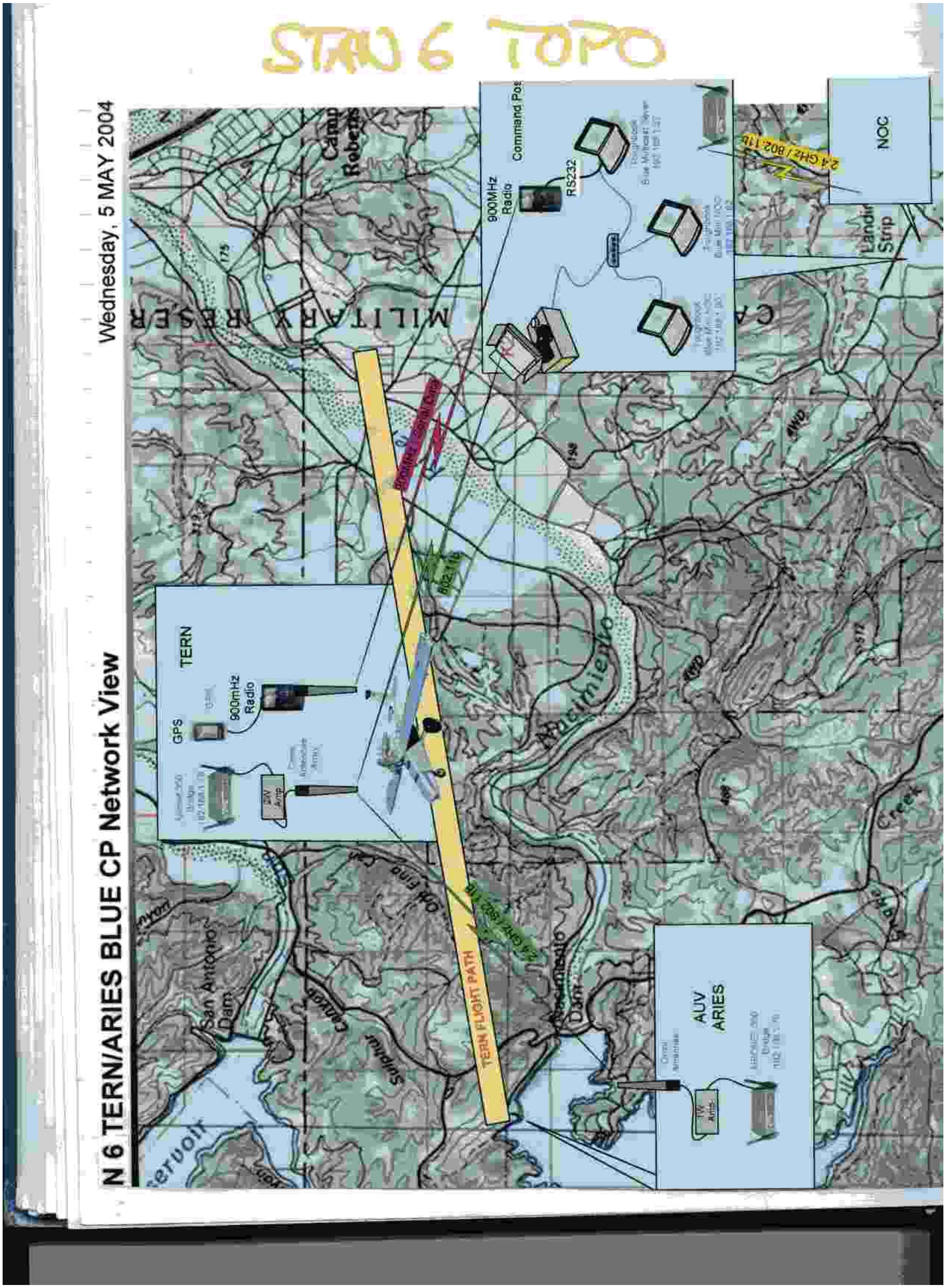
Location: LAT 35 44.637 LONG 120 55.967 distance to the balloon 4.72 km
Was able to reacquire the Balloon bridge indicating that the larger packet size is now acceptable
Enable SNMP on the tablet PC
Throughput is set to 1 mbps

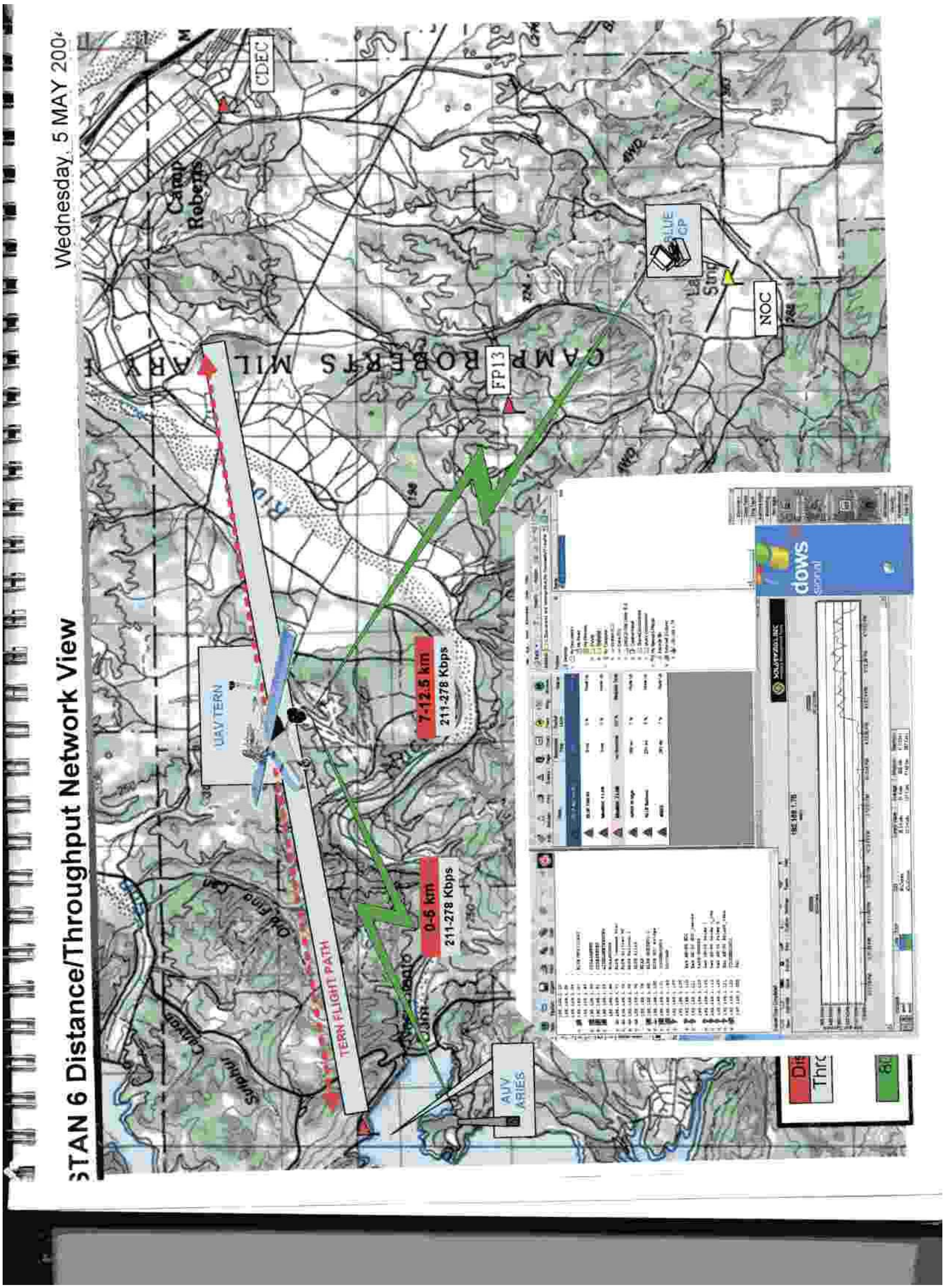
1216 Altitude of the balloon is 556 m

File Size (MB)	Time (sec)	Mbps	Time
2.852	117	0.195009	
2.852	119	0.191731	
2.852	133	0.171549	
2.852	111	0.20555	Downloads using ftp
953	35	217.8286	
6.16	327	0.150703	

-o- k2 / CP Locations -o- Balloon Location -o- ARIES network path




STAN 6 TOPO
N 6 TERN/ARIES BLUE CP Network View
Wednesday, 5 MAY 2004
Camp Roberts
MILITARY RESER
Command Post
900MHz Radio
RS232
2.4 GHz / 802.11b
NOC
Landing Strip
TERN
GPS
900mHz Radio
2W Amp
802.11b
TERN FLIGHT PATH
San Antonio Dam
AUV ARIES
Creek


STAN 6 Distance/Throughput Network View
Wednesday, 5 MAY 2004
CDEC
Camp Roberts
BLUE CP
NOC
FP13
CAMP ROBERTS MILITARY
UAV TERN
TERN FLIGHT PATH
7-12.5 km
211-278 Kbps
0-6 km
211-278 Kbps
AUV ARIES

STAN 7 PLANS 20.05.04

- Cameras on UAV

- networking MAR
  OFDM

ADHOC → AUV
UAV ↗ blimp
Infrastructure 802.11b → UAV / SWIFT
→ Alo

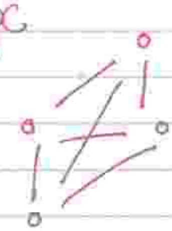
URBOT ?

SWC → AC tracker

tracker follows on

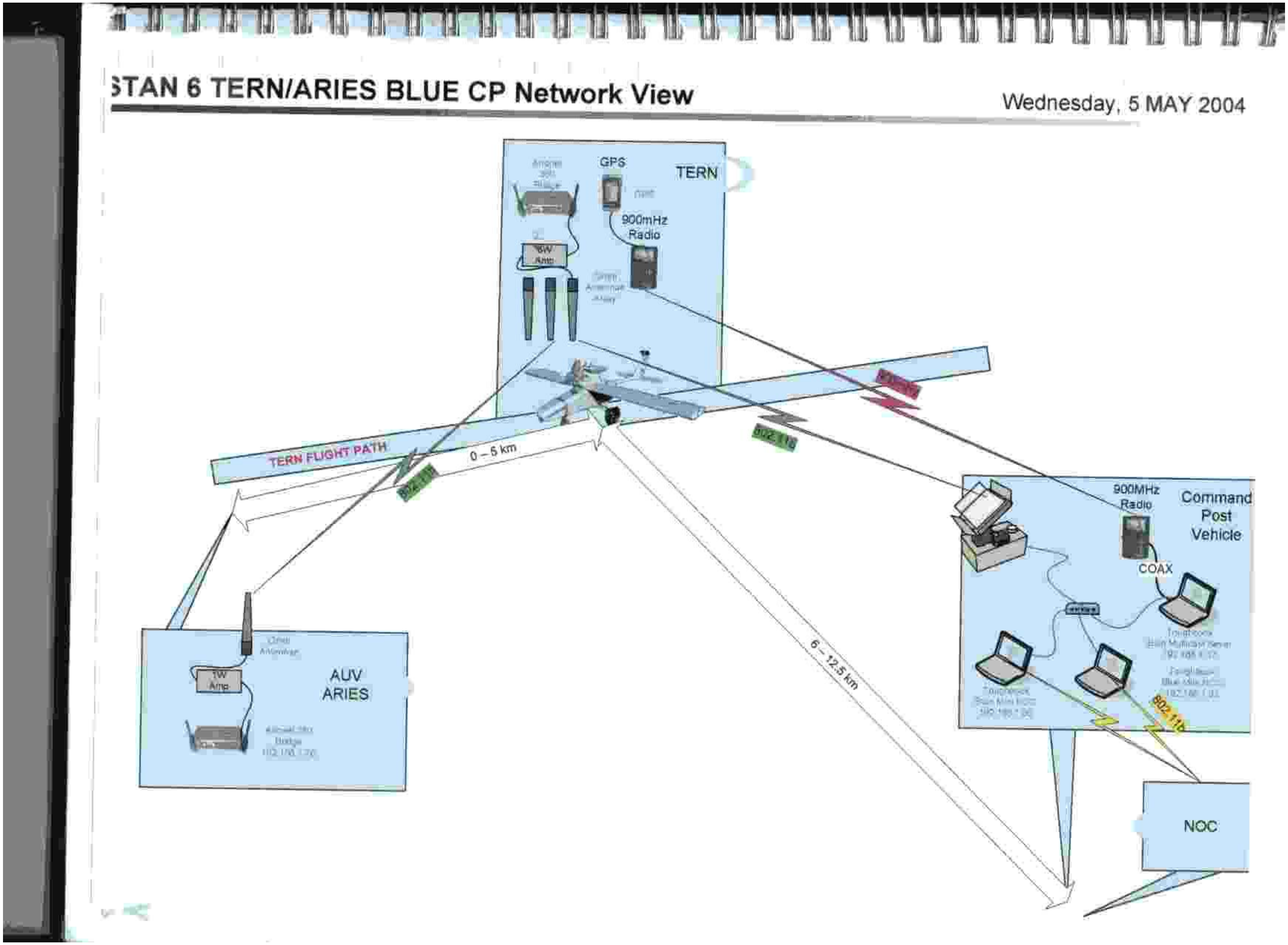
o balloon

DOC
Grid



o mesh - infrastructure

WiFi-Plus.com


STAN 6 TERN/ARIES BLUE CP Network View
Wednesday, 5 MAY 2004
TERN
GPS
900mHz
Radio
6W
Amp
TERN FLIGHT PATH
0 – 5 km
802.11b
6 – 12.5 km
900MHz
Radio
Command
Post
Vehicle
COAX
802.11b
AUV
ARIES
1W
Amp
NOC

D:\wpdocs\Aero\Netzer-tern\power.wpd   Thursday, January 22, 2004

AirMagnet Sensor NL-5354AP Aries		2.125 lb	12V @ 1A = 12W
Cisco Aironet 350		1.3 lb	48V 125ma = 6W
Cisco Router with fan		1.375 lb	1.037A @ 12V = 12.44W
Without fan			1.17lb 1.05A @ 12V = 12W
Amplifier		1.3 lb	12V 300ma = 6W receive 12V @ 2.8A = 33.6W
Batteries	#1	2.15 lb	12 & 24V nominal 14.8 max ea @2A
	#2	2.15 lb	
	Total	6.1 lb + batteries	
		4.3 lb batteries	
	Total	10.4 lb	36.4W to 64.04 W in receive to transmit mode
Box	2lb 13 Oz	2.813 lb	
	Total w Box	13.21 lb	plus cables

48W max from each battery before blow!

Absolute minimum in nose	1.3 +2.18 = 4.11	
Nose weights now	6 lb	

Issues
When
What
Who

Reference		
Fan	3.2 oz	12V @ 0.34A = 4.08W
Cisco Naked	1 lb 2.6 oz	

12V 24.4W and 33.6W

Thursday, February 12, 2004 D:\wpdocs\Aero\Tern Router\newpower.wpd

AirMagnet Sensor NL-5354AP Aries	2.125 lb	12V @ 1A = 12W
Cisco Aironet 350	1.3 lb	48V 125ma = 6W
Cisco Aironet 350	1.3 lb	48V 125ma = 6W
1 W amplifier	1 lb	24V 5W max
Amplifier	1.3 lb	12V 300ma = 6W receive 12V @ 2.8A = 33.6W
Freewave	0.8lb	180ma transmit 100ma receive 2.16W
Port	0.5 lb	0.5A @ 12V = 6W
Total	7.7 lb	70.76W Not including cables

****

converters		0.737lb	80-90%
Batteries	#1	2.15 lb	12 & 24V nominal 14.8 max ea @2A
Box	2lb 13 Oz	2.813 lb	
GPS		0.675 lb	neg

172.8 Watt-hours per battery x 2 = 345.6 Watt-hours
at 64.04 Watts 5.397 hours

12V @ 3.3A Wall Industries QAW24S12-40 40W
12V @ 2.5A Datel UHE-12/2500 30W
48V @ 167ma 8W 8W 5.8 oz for Wall and Pico

01.06.2004

STAN 6 Report / Generation 2 Test

- Combined Research Objectives
  Proof of Concept for AirBorne Network Node
  - isolated test (Lake Nacimiento) short - medium - long
  - interference exclusion testing with TERN
  - long-range TERN AirBorne with NOC integration

- particular objectives to Alex →

From: Netzer, Dave USA **Sent:** Thu 5/27/2004 1:31 PM
To: brian.l.kent@us.army.mil; dan@inter-4.com; Blazevich, Ryan USA; Bordetsky, Alex USA; Manuel, Chris USA; tonyh@sncorp.com; ralph@inter-4.com; kyle.longcrier@us.army.mil
Cc:
Subject:
Attachments:

All:

Want to clarify some points regarding the ground network. My understanding is that SNC/INTER-4/Redline will provide the ground network for the 24-30 August part of STAN 7. I do not know if the ground network to be used by the Rangers, etc. is Redline or K4 based. That being said, let me tell you what we currently plan from the NPS side to see what the best overall solution can be. We plan to install Redline AN-50 OFDM units at several locations; NPS, CIRPAS in Marina, MOUT/Log area at Fort Ord, mid-Salinas Valley (relay), and Camp Roberts TOC. We may also be putting one at the SATCOMSTA for connectivity and reachback capability. We hope to have this installed a month ahead of time (assuming we can get the sole source purchase through the mill in time) so that we can test it out and have it ready for the experiments from 19-23 August.

We also will have 802.11b from the ARIES and SEALs in Monterey Bay (ARIES linked to NAVBOARD/SEALs via low-rate acoustic modem). At Camp Roberts we will have (we hope) the SOCOM/VC-6 TERN, the NPS TERN, a smaller UAV with turret camera, NPS tethered balloon, manned Aerosphere, Pelican surrogate Predator, NG LLDR on the network, HDTV under balloons, etc. We will have the primary NOC at NPS in the GIGA Lab. "Satellite NOCs" will be at the MOUT City and Camp Roberts. We hope also to have a SEGOVIA satellite link between the various sites.

This is why we want to put in a somewhat permanent ground network based on OFDM.

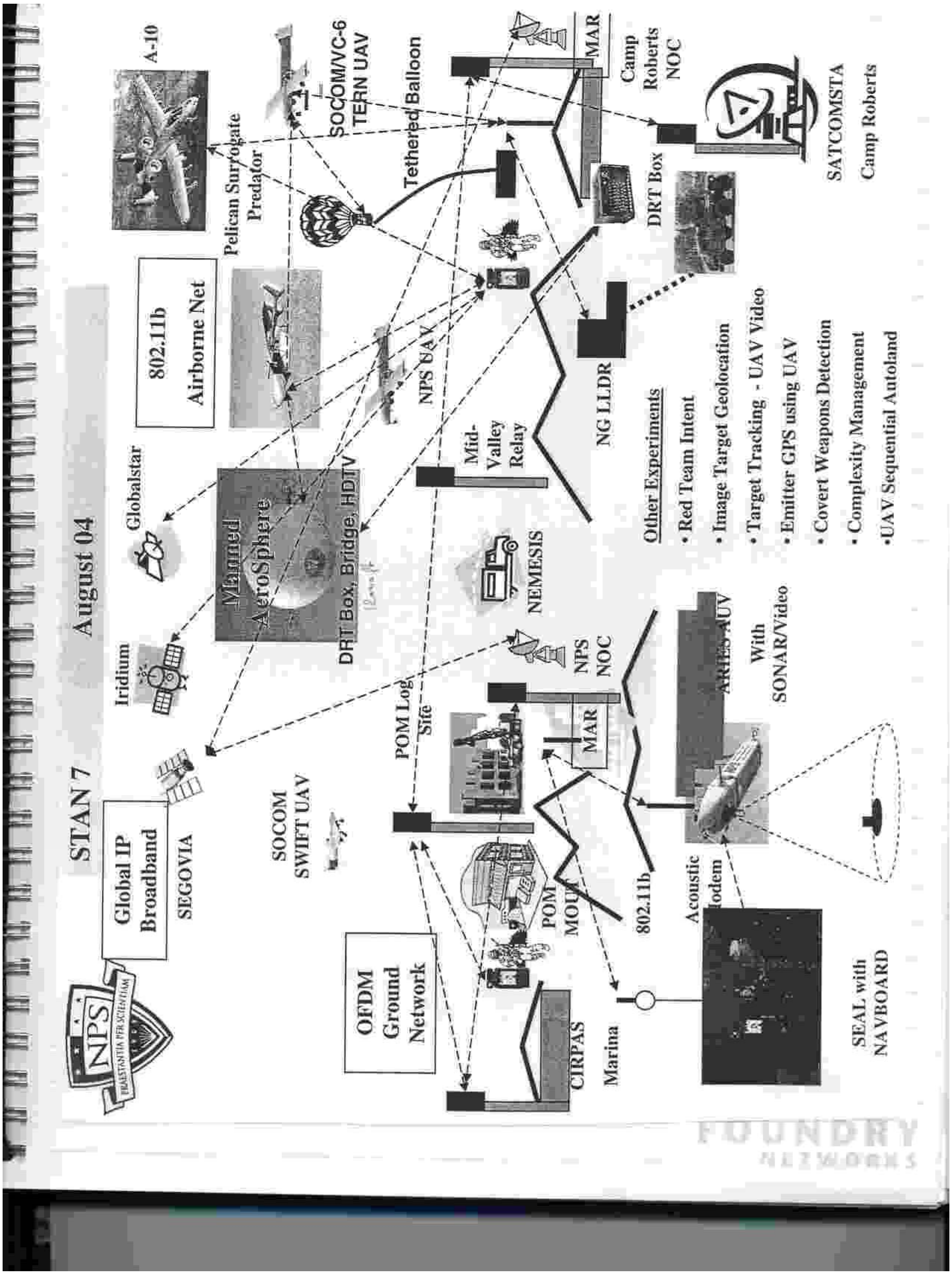
Question is; will this be adequate for your ground network backbone? If partially so, what additional components will SNC/INTER-4/Redline need to provide?

Meeting with the POM fire, police, etc. on Friday to work out any final concerns of theirs before the use request is approved.

FAA has told me that we are clear to operate the SWIFT at the MOUT and Log sites (with a little coordination).

Chris and I will be working the A-10 possibility with AFRL, etc. in the next two weeks.

Dave


STAN 7
August 04
NPS
PRAESTANTIA PER SCIENTIAM
Global IP Broadband
SEGOVIA
Iridium
Globalstar
802.11b
Airborne Net
Pelican Surrogate Predator
A-10
SOCOM/VC-6 TERN UAV
Tethered Balloon
MAR
Camp Roberts NOC
SATCOMSTA
Camp Roberts
DRT Box
NG LLDR
NPS UAV
Mid-Valley Relay
Manned AeroSphere
DRT Box, Bridge, HDTV
NEMESIS
NPS NOC
POM Log Site
MAR
ARIES AUV
With SONAR/Video
SOCOM SWIFT UAV
OFDM Ground Network
POM MOUT
802.11b
Acoustic Modem
CIRPAS
Marina
SEAL with NAVBOARD
Other Experiments
• Red Team Intent
• Image Target Geolocation
• Target Tracking - UAV Video
• Emitter GPS using UAV
• Covert Weapons Detection
• Complexity Management
•UAV Sequential Autoland
FOUNDRY
NETWORKS

STAN 7 AUG 19-23

A couple of thoughts to discuss with Dave and Chris on the research tasks for our team:

1. In comparison with standalone airborne, ground, and underwater long-haul wireless nodes that we tested at STAN 6 we are going to have small airborne net (Air Sphere balloon, Pelican, and Tern), ground net (OFDM long-haul backbone, mesh cluster at three sites), and underwater mesh.

2. We will also have small network of NOCs (NPS NOC, Ft Ord TOC/NOC, Camp Roberts UoC) capable of collaboration and data sharing across command and control infrastructure.

3. The research tasks naturally group around feasibility of layered networking infrastructure working together providing multipath adaptation, and situational awareness sharing. Integration of underwater SA with the littoral SA becomes central to the study.

4. As MAR is been somewhat tested for switching between OFDM, 802.11, and Iridium, we'll be able to set up MARs at the OFDM/Ground mesh cluster gateway nodes and also practice the CoABS switching between different links via the SA interface.

5. The network of NOCs stretched to remote TOCs will be provided by OFDM and near-broadband satellite links which will test first time.

5. At STAN 6 we learned how to reach the remote site by stretching the mesh locally. What we don't know yet, is how to get to the ground sensor mesh via the layers of airborne-ground-underwater nodes. That's exactly what we can explore at STAN 7.

6. I also suggest at STAN 7 to start using the OFDM-local clusters mesh for reaching to the remote sensors (LLDR and Video) and operating them. The LLDR from Northrop Grumman will be a good node to work with.

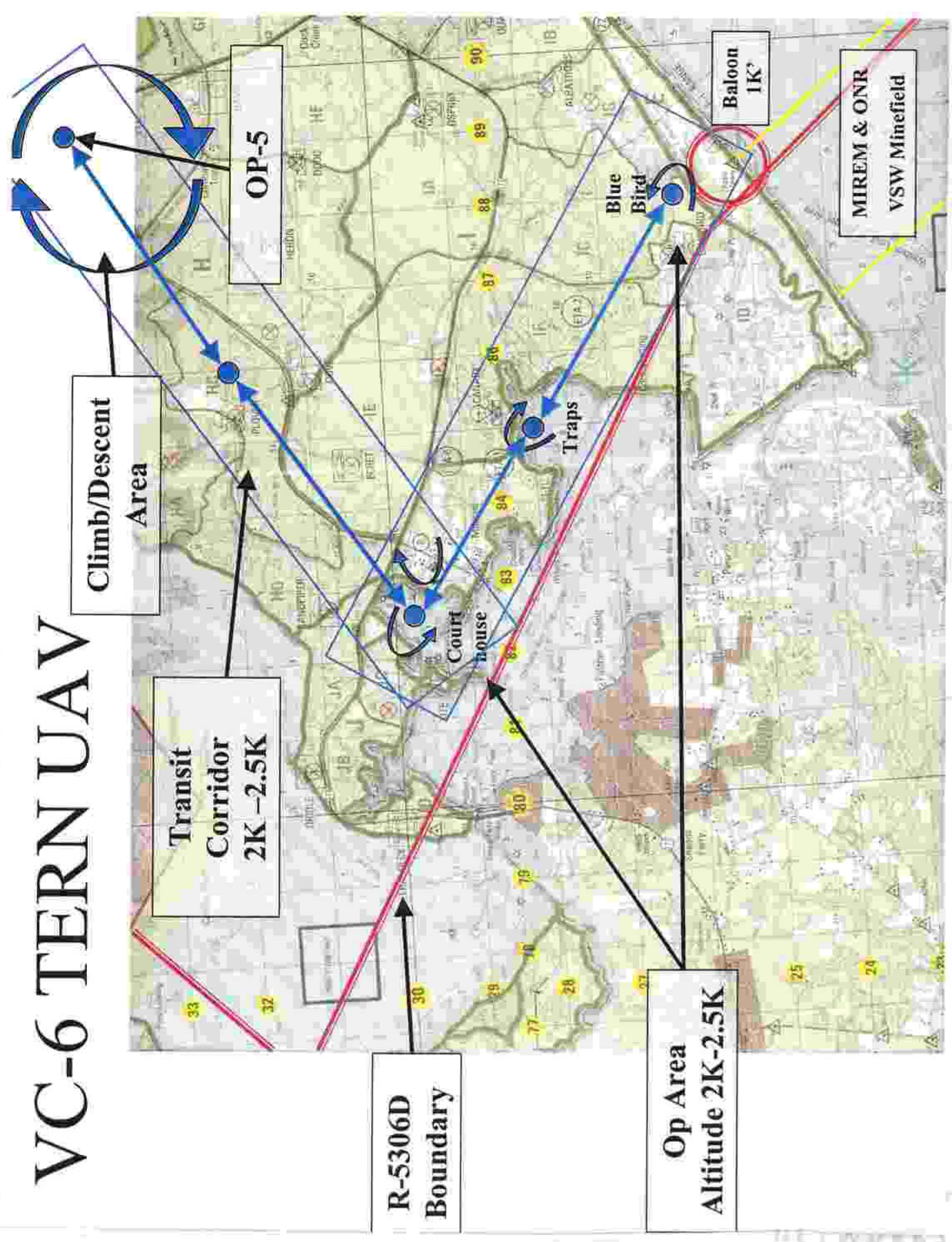
7. We'll also prototype using mesh for delivering Globalstar/Iridium links down to every TACTICOMP via the root laptop/TAC-PAK unit.

5/27/2004

Power / Weight /

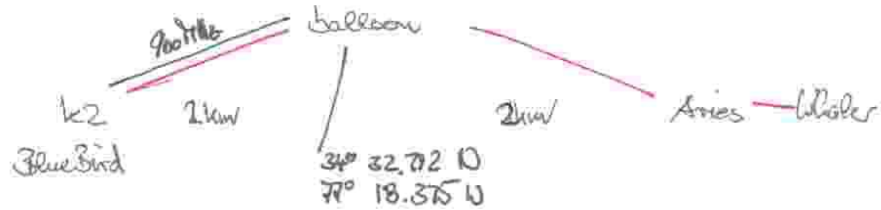
802.11g TERN / Balloon

Camp Lejeune (planned TERN ops) 05.06.2004



Camp Lejeune

06.06 ~~Short~~-range setup



k2 not reading multicast message (GPS) → manual mode

Run	Time (local)	File Size (MB)	Transfer Time (sec)	Transfer Rate (kbps)	K2 Position	Aries Position	Balloon Position	screenshot files
1	1141	2.78	64	347.5	34°33.250'N, 077°19.572'W	Blue Bird	34°32.792'N, 077°18.375'W	05.jpg
2	1144	2.78	67	331.9	34°33.250'N, 077°19.572'W	"	34°32.792'N, 077°18.375'W	06.jpg
3	1147	7.47	172	347.4	34°33.250'N, 077°19.572'W	"	34°32.792'N, 077°18.375'W	07.jpg
4	1151	7.47	169	353.6	34°33.250'N, 077°19.572'W	"	34°32.792'N, 077°18.375'W	08.jpg
average				345.1				

k2 (not reading multicast): send request to SWC for support (Jack, Rick, Dave)

Run	Time (local)	File Size (MB)	Transfer Time (Sec)	Transfer Rate (Kbps)	K2 Position	Aries Position	Balloon Position	Screenshot files	Comments
1	1257	2.78	49	453.9	34°40.455'N, 077°22.283'W	Blue Bird	34°32.792'N, 077°18.375'W	11.jpg	34° 32' 47.52" / 077° 18' 22.5"
2	1259	2.78	54	411.9	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	12.jpg	
3	1303	7.47	128	486.9	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	13.jpg	
4	1307	2.78	50	444.8	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	14.jpg	
5	1308	7.47	74	807.8	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	15.jpg	
6	1311	7.47	95	629.1	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	16.jpg	
7	1314	6.17	78	632.8	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	17.jpg	
8	1315	6.17	80	617.0	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	N/A	
9	1318	6.17	64	771.3	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	18.jpg	
10	1323	19.1	248	616.1	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	19.jpg	
11	1329	19.1	252	606.3	34°40.455'N, 077°22.283'W	〃	34°32.792'N, 077°18.375'W	20.jpg	
12	1333	19.1	N/A	N/A	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	21.jpg	Aries moved during run. At time=90sec link lost, regained at time=130sec. Guard Boat 4 reported Aries antenna submerged during this time. File xfer aborted.
13	1344	2.78	40	556.0	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	22.jpg	
14	1346	2.78	50	444.8	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	23.jpg	
15	1347	2.78	41	542.4	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	24.jpg	
16	1349	7.47	76	786.3	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	25.jpg	
17	1351	7.47	100	597.6	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	26.jpg	Aries was being moved during this run
18	1353	7.47	87	686.9	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	27.jpg	Balloon showing 4% packet loss (0% packet loss during all previous runs). Aries showing 5% packet loss.
19	1357	19.1	N/A	N/A	34°40.455'N, 077°22.283'W		34°32.792'N, 077°18.375'W	28.jpg	Run taken while balloon being lowered and while Aries getting underway.
Average				602.4					
				71.7%	improvement vs. 1st runs				

FOUNDRY NETWORKS

07.06.2004 Long-Range Test along Coast (South)

K2-to-Balloon 802.11b Tests
7 June 04

Posit #	Date	Time (local)	Location Name	K2 Position	Balloon Position	Range to Bluebird (km)	screenshot files	comments
1	6/7/04	1015-1100	South Topsail Beach	34°20.983'N, 077°38.855'W	34°32.792'N, 077°18.375'W	37.2	none	Unable to establish 2.4GHz 802.11b link. Successfully received 900MHz Freewave signal from balloon at South Tower.
2	6/7/04	1120-1140	Jolly Roger Pier	34°21.900'N, 077°37.657'W	34°32.792'N, 077°18.375'W	34.7	none	Unable to establish 2.4GHz 802.11b link. Axel changed the transmit power on the K2 from 30mW to 50mW with no effect. Changed settings back to 30mW.
3	6/7/04	1200-1210	Surf City South	34°23.600'N, 077°35.577'W	34°32.792'N, 077°18.375'W	30.3	none	Unable to establish 2.4GHz 802.11b link.
4	6/7/04	1235-1245	Surf City Pier	34°25.453'N, 077°32.688'W	34°32.792'N, 077°18.375'W	24.7	none	Unable to establish 2.4GHz 802.11b link.
5	6/7/04	1315-1400	North Topsail Beach	34°27.652'N, 077°29.082'W	34°32.792'N, 077°18.375'W	17.9	01.jpg - 07.jpg (see note 2)	Successfully established 802.11b link with balloon at South Tower. See Note 2.

Notes
1. Atmospheric conditions were extremely hazy and humid.
2. The following screen shots were saved:
   a. 01.jpg: Saturating Balloon bridge with 3Mbps. Showing ~1Mbps throughput
   b. 02.jpg: Saturating Balloon bridge with 3Mbps. Repositioned antenna to point approx. 3° CCW from previous run. This improved link quality. Packed loss down to 45%
   c. 03.jpg: Saturating Balloon bridge with 3Mbps. Repositioned antenna to point additional 3° CCW from previous run. This improved link quality further. Packed loss down at 50%
   d. 04.jpg: Changed power out from Balloon bridge from 50mW to 30mW. This further improved link quality and decreased packet loss to ~42%
   e. 05.jpg: Changed Balloon bridge settings: Set 11Mbps Packet Size to "Not Allowed" and set RTS Threshold to "Zero". Restarted Saturation Test. This further improved link quality and decreased packet loss to ~25%. However, Response Time seems to have increased.
   f. 06.jpg: Changed Packet Size from 5000 bits to 1000 bits. This caused a decrease in link quality.
   g. 07.jpg: At time 1350 Local, Balloon appears to be going down as link quality steadily deteriorates. Link dropped at 1353.

—JOLLY ROGER PIER—

803 Ocean Blvd.
Topsail Beach, NC
(910) 328-4616

~~home 619.806.~~
home 619.696.8121
work: 619.524.2985

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marshallp@saic.com
www.saic.com

08.06.2004 LWTC

Lab Test Tern Payload:
Lab TERN screenshot 22.jpg , Pelco Video only (~250kbps) see →

CJTFEX 04-2
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Camp Lejeune

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todd@valdes.net
Todd A. Valdes
Deputy Attorney General
todd.valdes@doj.ca.gov
(213) 897-2635
CALNET 8-647-2635
FAX (213) 897-2802

NETWORKS

08.06.04

Current Measure PayLoad TERN

– Setup:

[$U = 12V$]

$I_1 = 1.150$ ($t = 0 \ldots 1$ [min])
$I_2 = 1.200$ ($t = 1 \ldots 2$)
$I_3 = 1.300$ ($t = 2 - 2.5$)
$I_4 = 1.800$

Boot complete $I = I_4 - 1.812$
Network idle $I_{min} = 1.3$ A
(pelco on) $I_{max} = 1.912$ A
$I_{AVG} = 1.571$

(pelco off) $I_{min} = 0.844$ A
$I_{max} = 1.072$ A
$I_{AVG} = 0.890$ A

Voltage Measure PayLoad

$U = 15.42$ (idle)
$U_1 = 15.26$ V ($t = 0.1 - 3$ [min])
$U_2 = 15.15$ V Boot complete
$U_{max} = 15.20$ V
$U_{min} = 15.08$ V
$U_{AVG} = 15.15$ V

Wattage

Network only: $P_{max} = I_{max} \cdot U_{max} = 1.072A \cdot 15.20V = 16.3W$
$P = U \cdot I$ $P_{min} = I_{min} \cdot U_{min} = 0.844A \cdot 15.08V = 12.7W$
} Network only avg. 14.5W

incl. Video. $P_{max} = I_{max} \cdot U_{max} = 1.912A \cdot 15.20V = 29.1W$
$P_{min} = I_{min} \cdot U_{min} = 1.300A \cdot 15.08V = 19.6W$
} Network + video feed (no camera) avg. 24.4W

www.ultralifebatteries.com

Batterie Specifications: UBI 2590 Lithium Ion (rechargeable)

30V @ 6Ah (28.8V)

15V @ 12Ah (14.4V)

~~UBI 5590 Lithium~~ (primary)

30V @ 11Ah 15V @ 22Ah

UBI 5390 Lithium MnO_2 (primary) (+56%)

Endurance:

Network only: UBI 2590 @ 14.5W

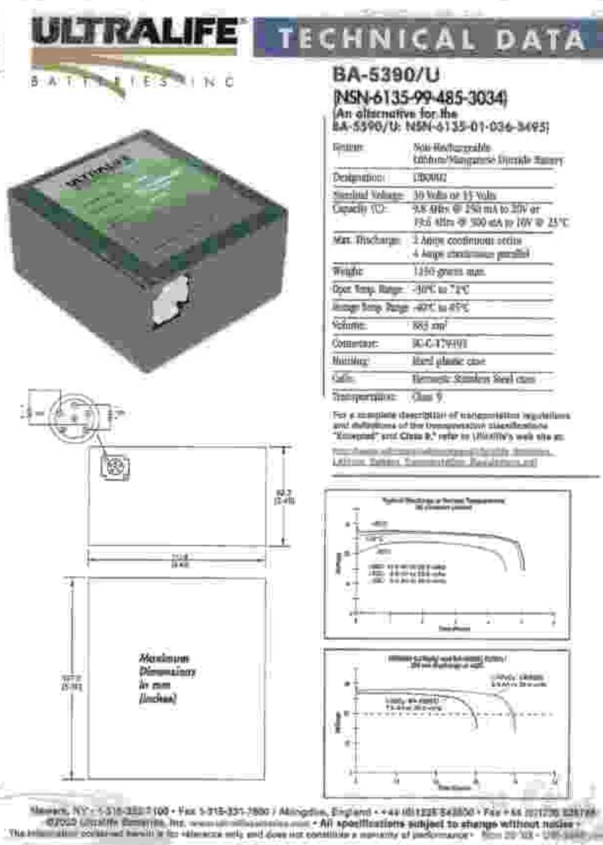
$I = \frac{14.6W}{14.4V} = 1.01A \Rightarrow 11.88h$

~~UBI 5890~~ = UBI5390: 21.78h

Network + Pelco: UBI 2590 @ 24.4W

$I = \frac{24.4W}{14.4V} = 1.69A \Rightarrow 7.10h$

UBI 5390: 13.02h


ULTRALIFE BATTERIES INC

TECHNICAL DATA

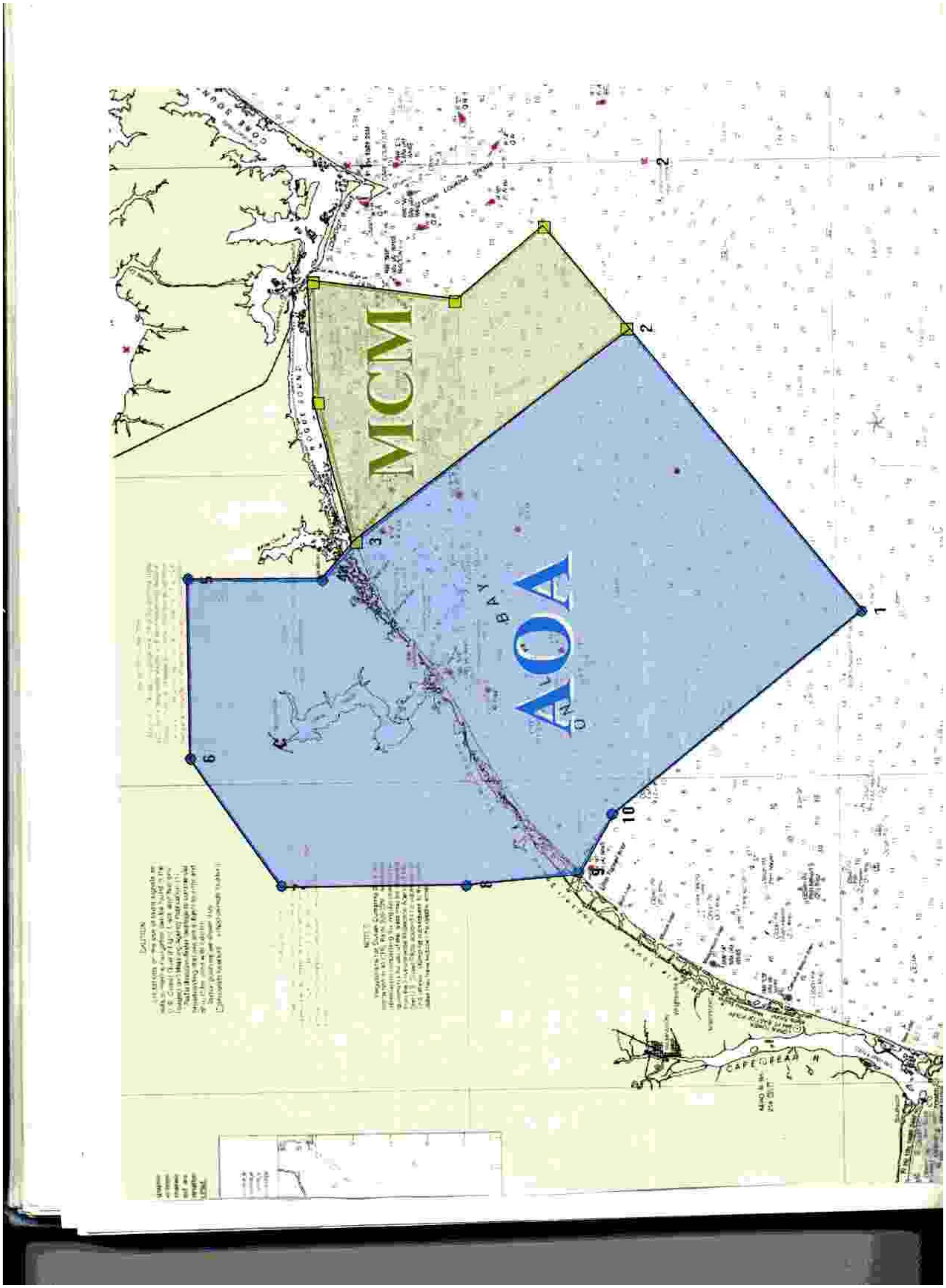
BA-5390/U

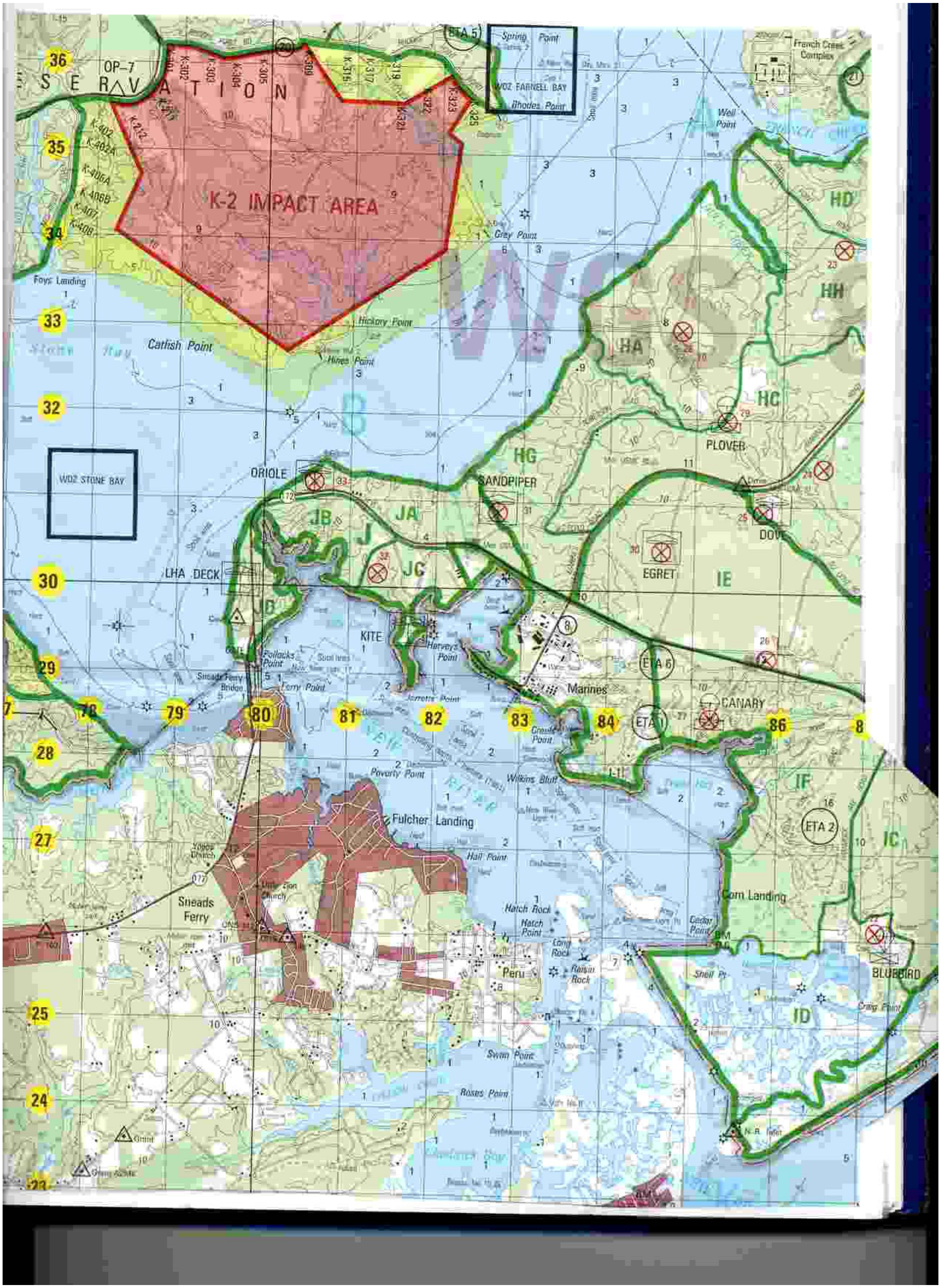
(NSN-6135-99-485-3034)

(An alternative for the BA-5590/U: NSN-6135-01-036-3495)

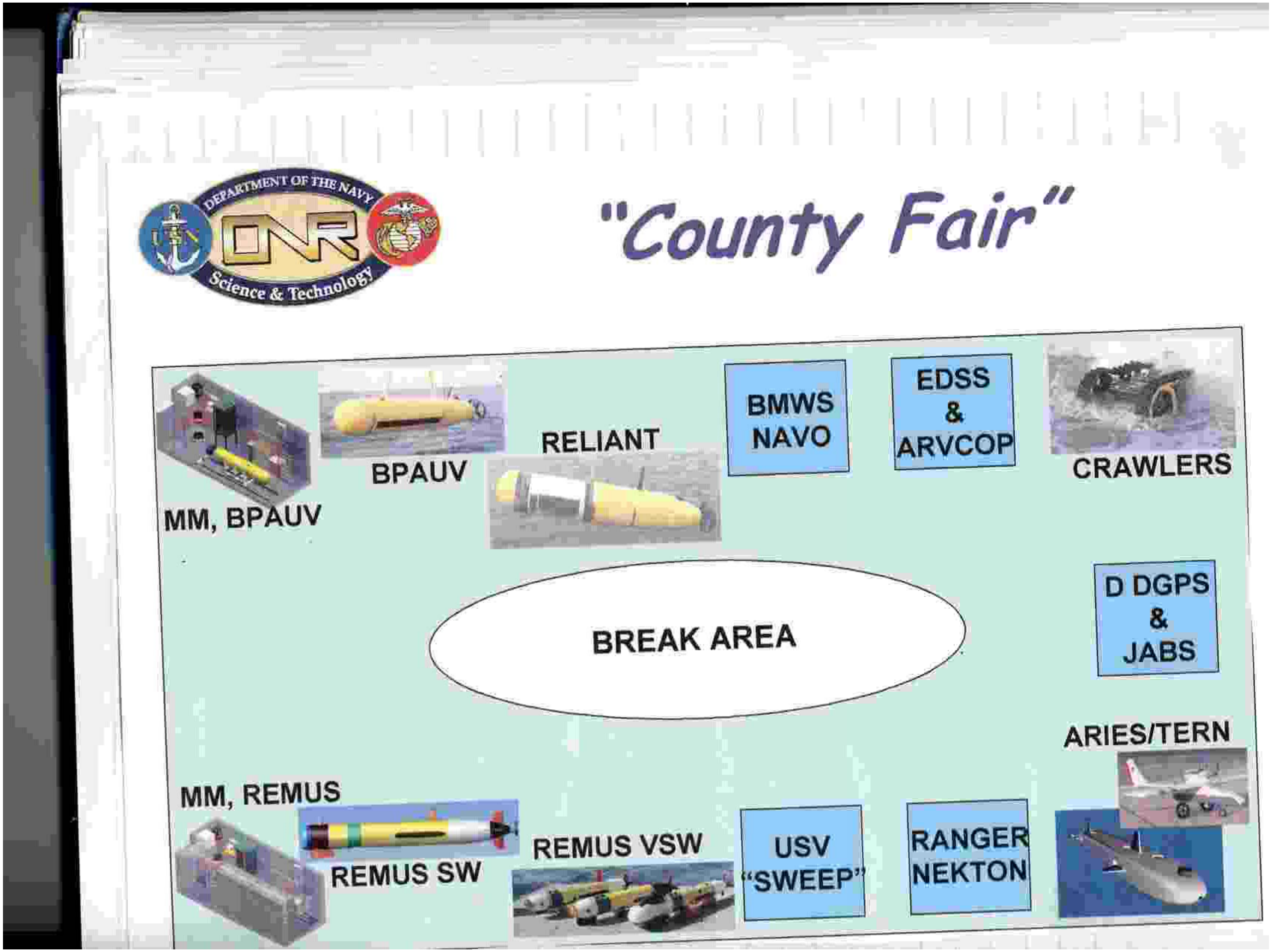
Designation:	[illegible]
Nominal Voltage:	30 Volts or 15 Volts
Capacity:	[illegible]
Max. Discharge:	[illegible]
Weight:	[illegible]
Oper. Temp. Range:	[illegible]
Storage Temp. Range:	[illegible]
Volume:	[illegible]
Connector:	[illegible]
Housing:	Hard plastic case
Cells:	Hermetic Stainless Steel cans
Transportation:	Class 9

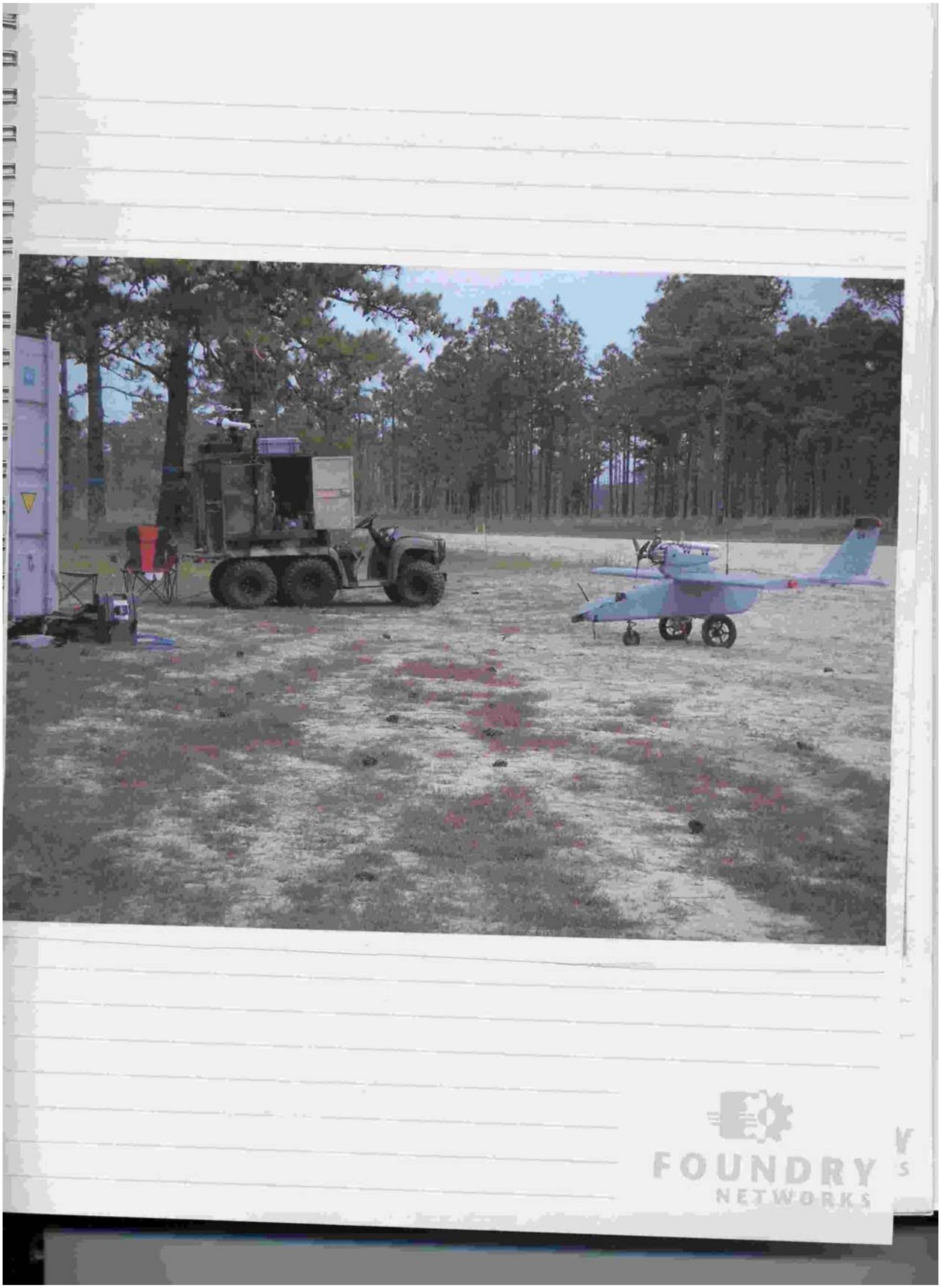
Maximum Dimensions in mm (inches)


MCM
AOA
1
2
3
6
9
10



K-2 IMPACT AREA
WOZ FARNELL BAY
Spring Point
Rhodes Point
WOZ STONE BAY
French Creek Complex
Grey Point
Foys Landing
Catfish Point
Hickory Point
Hines Point
ORIOLE
SANDPIPER
PLOVER
DOVE
EGRET
KITE
CANARY
BLUEBIRD
LHA DECK
Pollocks Point
Sneads Ferry Bridge
Ferry Point
Harveys Point
Jarretts Point
Marines
Poverty Point
Wilkins Bluff
Fulcher Landing
Hall Point
Hatch Rock
Hatch Point
Long Rock
Raisin Rock
Peru
Corn Landing
Cedar Point
Shell Pt
Craig Point
Swan Point
Roses Point
Sneads Ferry
ETA 5
ETA 6
ETA 2
OP-7
HA
HC
HD
HG
HH
IE
IF
IC
ID
JA
JB
JC

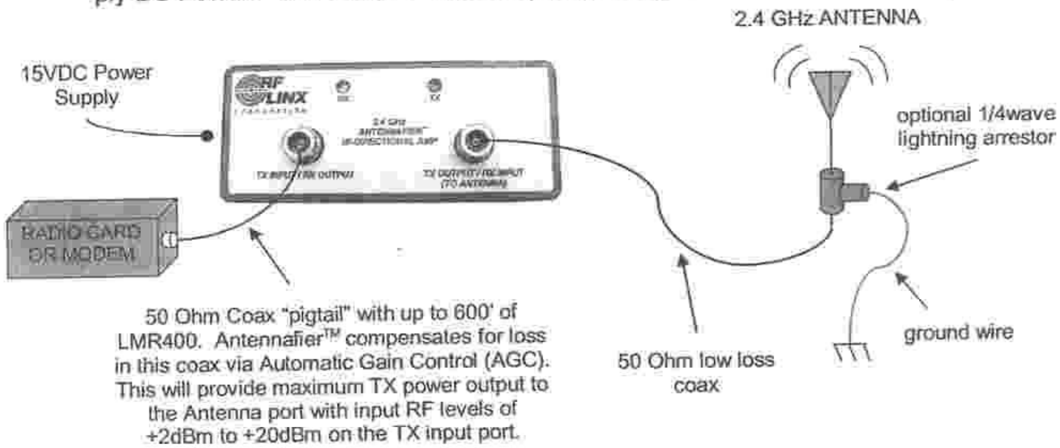

Department of the Navy
ONR
Science & Technology
"County Fair"
MM, BPAUV
BPAUV
RELIANT
BMWS
NAVO
EDSS
&
ARVCOP
CRAWLERS
BREAK AREA
D DGPS
&
JABS
ARIES/TERN
MM, REMUS
REMUS SW
REMUS VSW
USV
"SWEEP"
RANGER
NEKTON


FOUNDRY
NETWORKS

RF Linx 2 Watt amplifier specifications

2400 LE Series (Kit)
(1) 2400 LE Series Antennafier
(1) 15VDC Wall Mount Transformer (110VAC Input)
(1) Aluminum "L" Mounting bracket
(2) 1/4"x20 Stainless Steel Pan Head Screws

2400 LE (Connection)
Connecting a series 2400LE indoor Bi-Directional Amplifier is easy. Simply connect the Type 'N' female connectors to the appropriate RF ports as shown below and apply DC Power. The 2400 LE can be operate using 12VDC from a vehicle system.



2400 LE (Mounting)
Each Antennafier™ is supplied with an "L" shaped mounting bracket. This bracket attaches to the Antennafier™ back via two 1/4" x 20 Pan Head Screws. Then mount this assembly to either a wall or panel with the remaining holes located on the mounting bracket.

2400 LE (Operation)
The Antennafier™ is equipped with LEDs indicating either TX or RX mode of operation. When DC power is applied the green RX LED should be lit. The red TX light will only turn on when the amplifier senses an RF level of greater than +2 dBm on it's TX Input port. During normal RX/TX operation, one will see these two LEDs flicker back and forth between transmit and receive. If neither of these lights are operational check to ensure proper DC power is being applied.

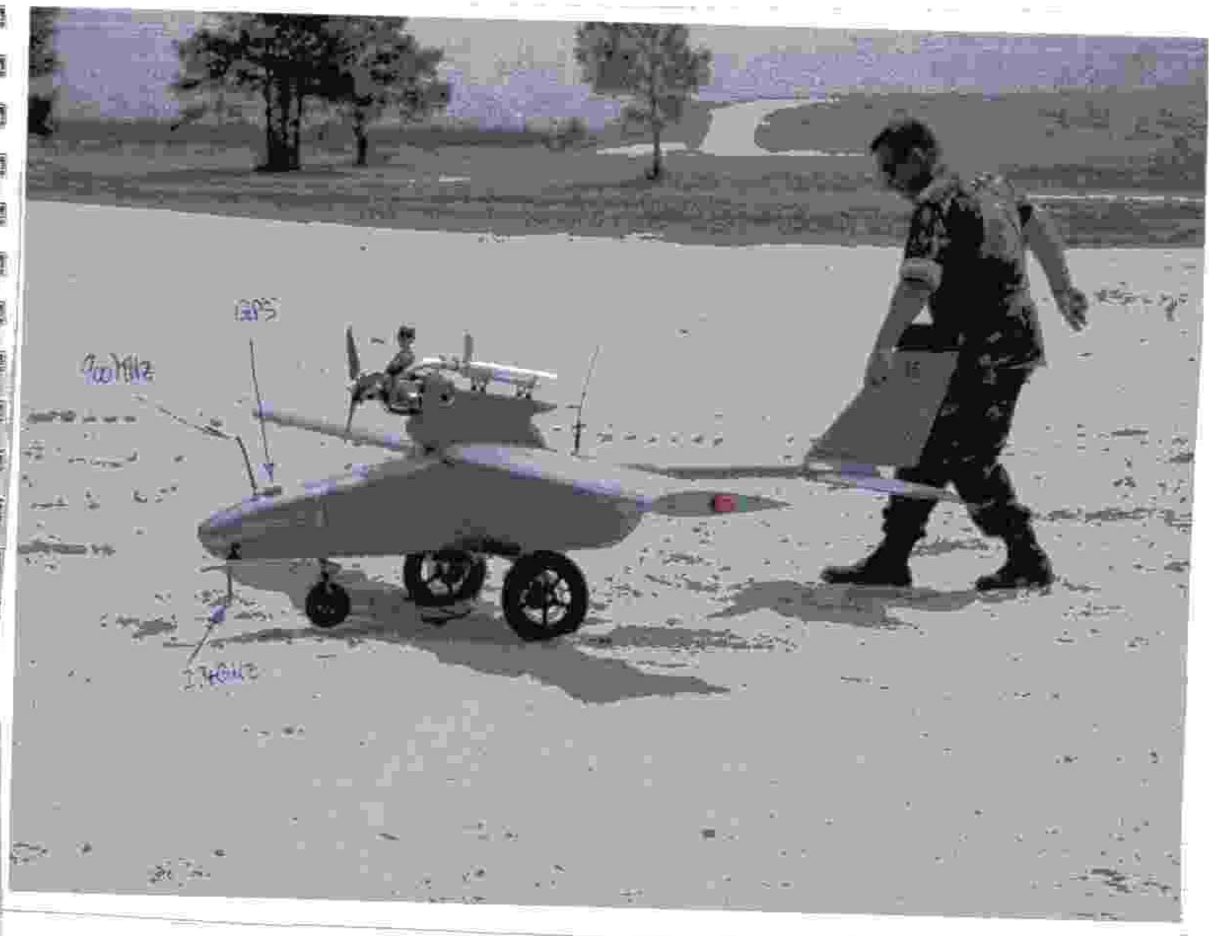
This amplification device is an RF subassembly. Its use in an RF system is subject to FCC approval.

9017 Cincinnati-Columbus Road
West Chester, Ohio 45069-3511
PHONE: (513) 777-2774
FAX: (513) 777-2115
Http://www.rflinx.com

March 12,2004

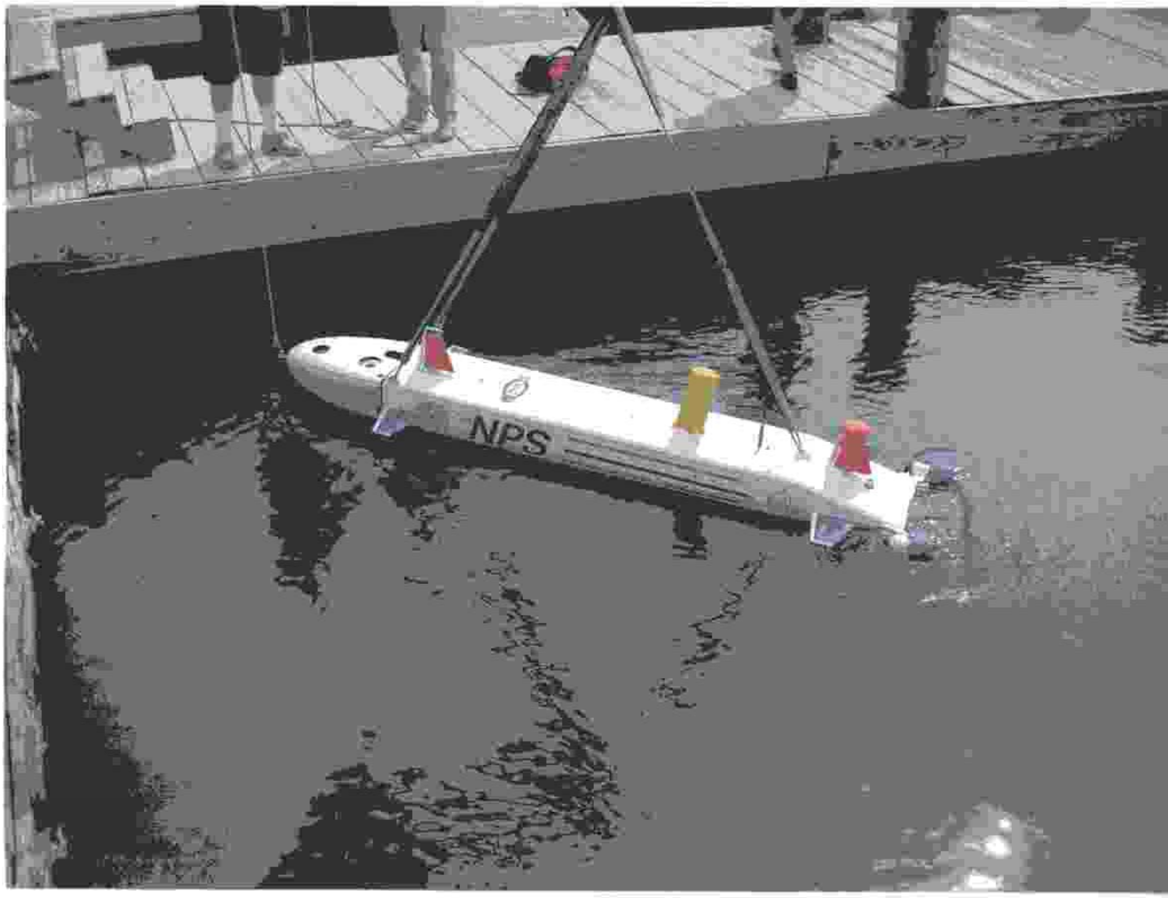
June 2004 Camp Lejeune, NC

GENERATION 3 OPERATIONAL
(video transmission with PELCO)

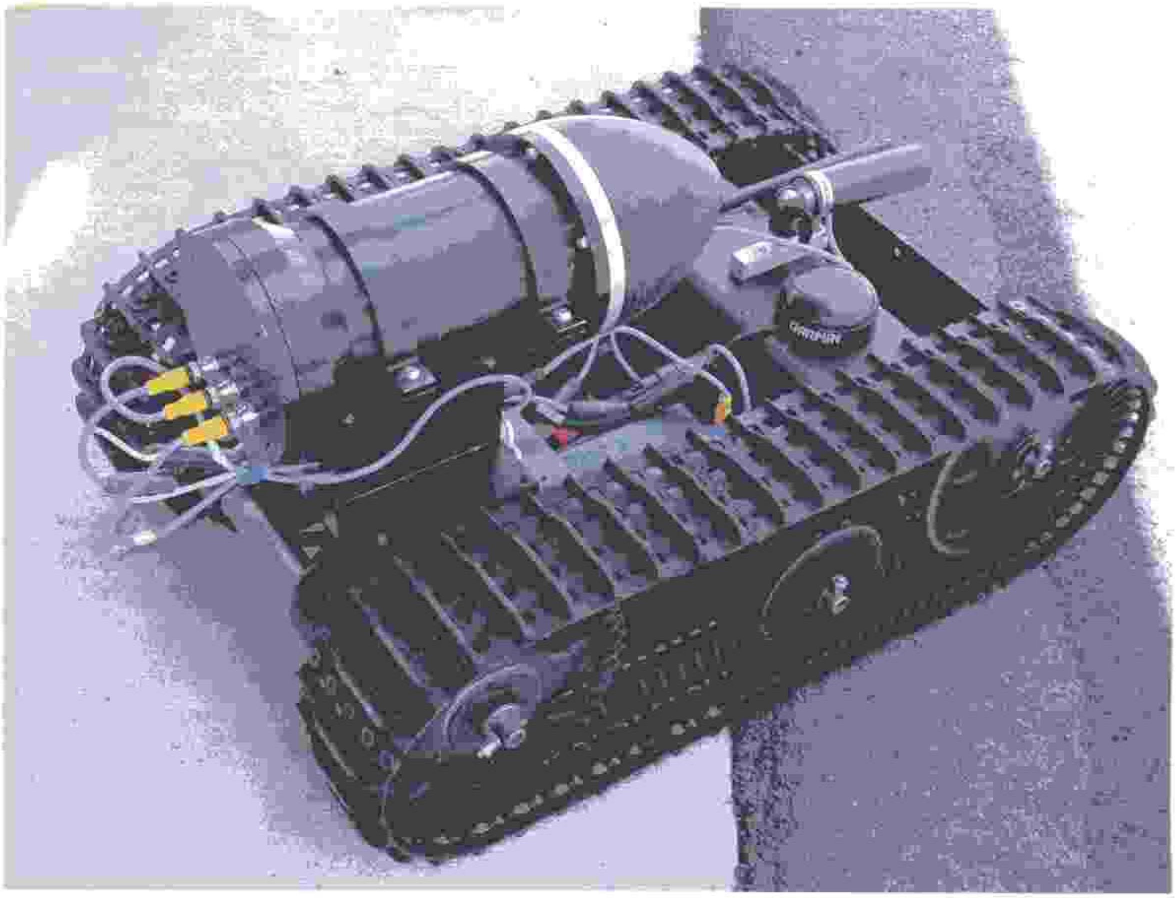


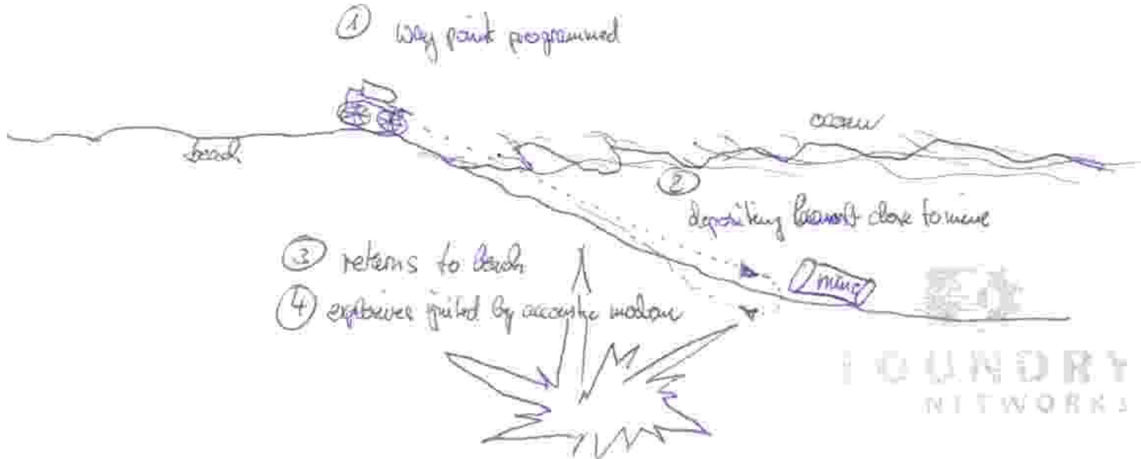
NO COMMENTS

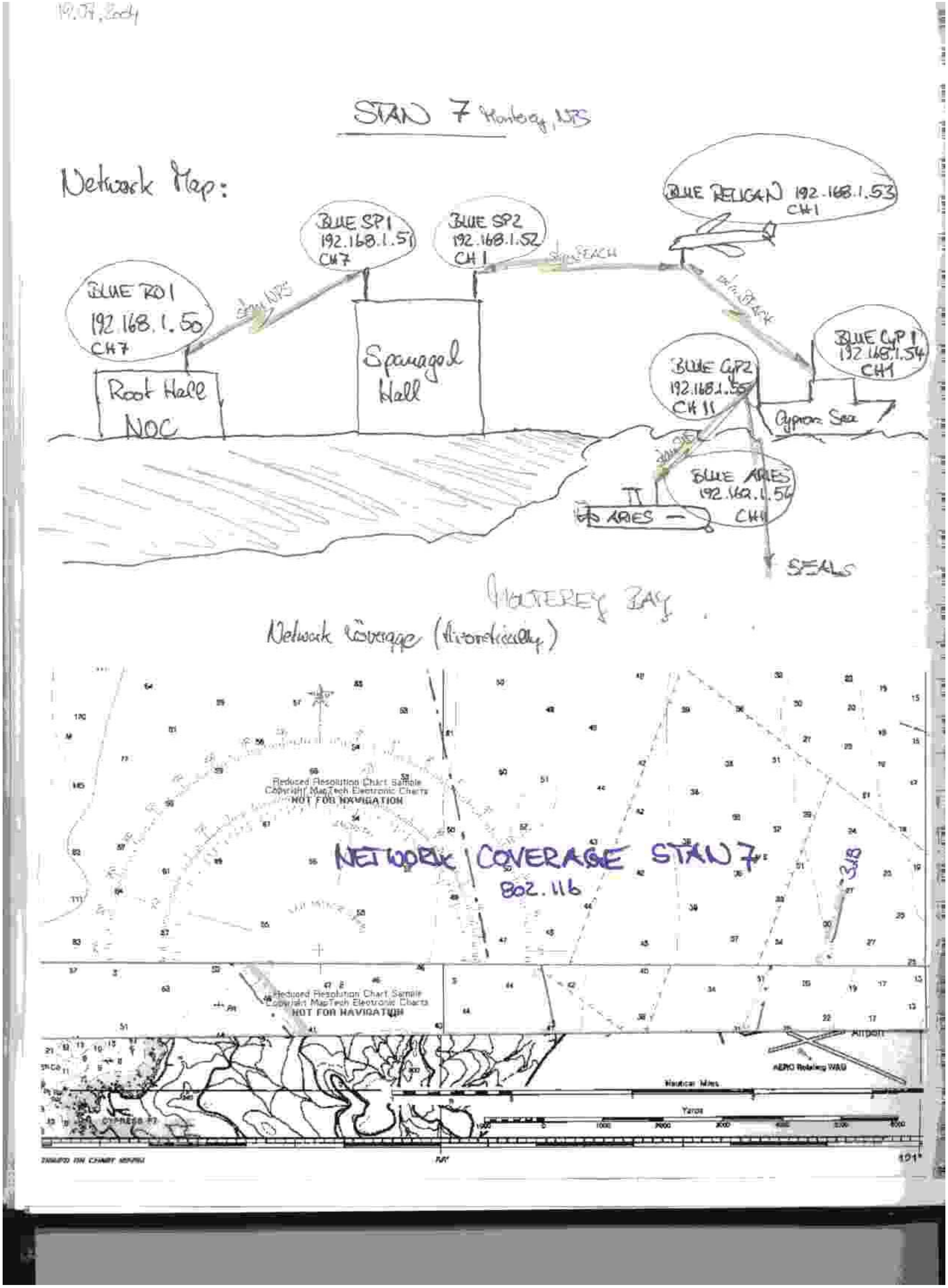
deploying ARIES (Camp Lejeune)



Crawler for mine clearance (with the „egg")






STAN 7 Monterey, NPS
Network Map:
BLUE RO1
192.168.1.50
CH7
BLUE SP1
192.168.1.51
CH7
BLUE SP2
192.168.1.52
CH1
BLUE PELICAN 192.168.1.53
CH1
BLUE CyP1
192.168.1.54
CH1
BLUE CyP2
192.168.1.55
CH11
BLUE ARIES
192.168.1.56
CH1
Root Hall
NOC
Spanagel
Hall
Cyprus Sea
ARIES
SEALS
MONTEREY BAY
Network Coverage (theoretically)
NETWORK COVERAGE STAN 7
802.11b
Reduced Resolution Chart Sample
Copyright MapTech Electronic Charts
NOT FOR NAVIGATION
Nautical Miles
Yards

Cambos for Sp Roof: 1921 / 145

to be mounted on Sp→beach

2.4 GHz 14 dBi Radome Enclosed Yagi

- Superior performance
- Light weight
- All weather operation
- 30° beam-width
- Can be installed for either vertical or horizontal polarization
- Includes tilt and swivel mast mount

Model: HG2415Y

Superior Performance

The HyperGain® HG2415Y Radome Enclosed Yagi Antenna features high gain and a 30° beam-width. It is ideally suited for directional and multipoint IEEE 802.11b and 802.11g wireless LANs and other systems operating in the 2.4 GHz ISM band. This antenna features a 12-inch coax lead terminated with a N-Female connector. Special Order Connectors are also available. The unique design of this antenna allows it to be installed for either vertical or horizontal polarization.

Rugged and Weatherproof

This antenna is enclosed within a UV-stable radome for all-weather operation. The HG2415Y antenna is supplied with a 60-degree tilt and swivel mast mount kit.

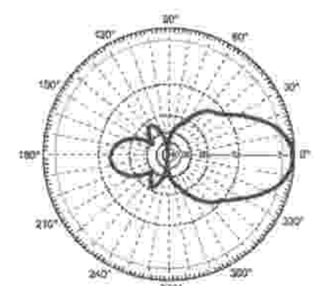
Electrical Specifications

Frequency	2400-2500 MHz
Gain	14.5 dBi
-3 dB Beam Width	45 degrees
Impedance	50 Ohm
Max. Input Power	50 Watts
VSWR	< 1.5:1 avg.

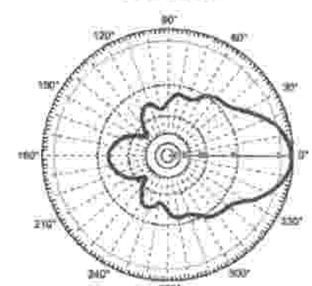
Mechanical Specifications

Weight	1.8 lbs. (.81 kg)
Dimensions Length x Diameter	18.2 x 3 (inches) 462 x 76 (mm)
Radome Material	UV-inhibited Polymer
Mounting	2" (50.8 mm) dia. mast max.
Polarization	Vertical and Horizontal
Wind Survival	>150 MPH

Antenna Gain Patterns



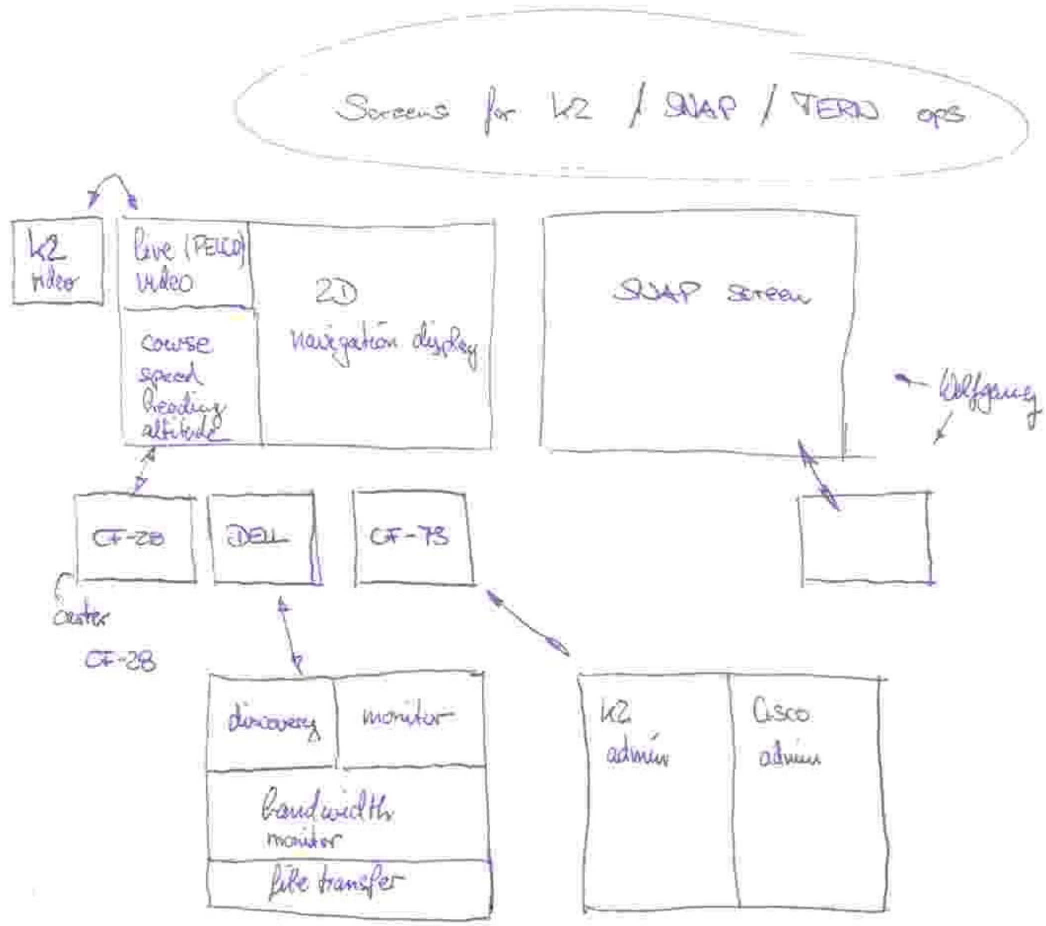
Vertical



Horizontal

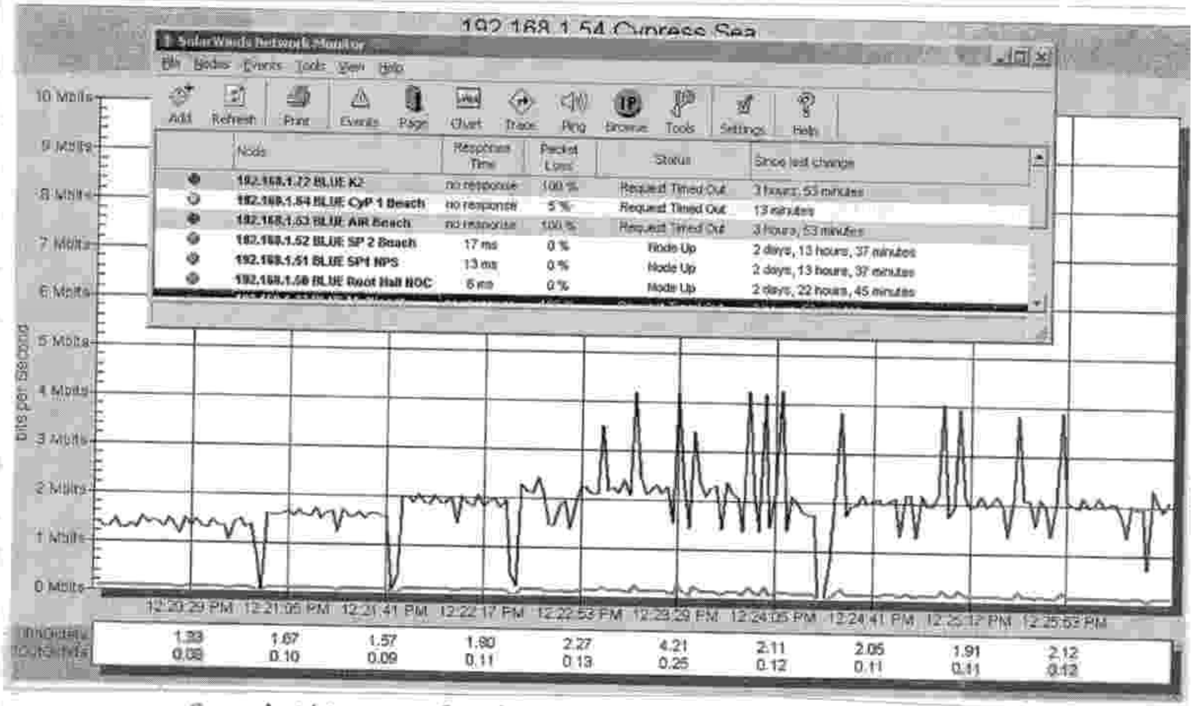
Guaranteed Quality

This product is backed by Hyperlink's Limited Warranty


Screens for K2 / SNAP / TERN ops
K2 video
live (PELCO) video
2D navigation display
course speed heading altitude
SNAP screen
Wolfgang
CF-28
DELL
CF-73
center CF-28
discovery
monitor
bandwidth monitor
file transfer
K2 admin
Cisco admin

22.07.04 NOC → Spanagel → Cypress Sea

Root Hall – Spanagel Hall – Fishermen's Wharf ↔ Aquarium



Current Value: 2.10 Mbps

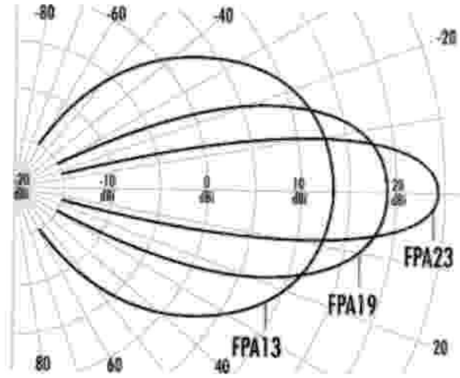
Average 1.50 Mbps

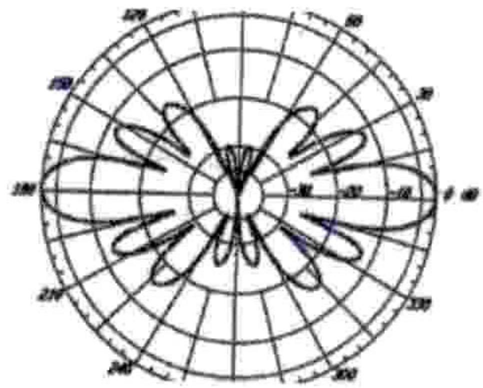
Minimum: 5.2 kbps

Maximum: 6.3 Mbps

Camp Lejeune

01.06. travel
2+3. setup
4.+5. initial testing
6.-9. operation
10+11. clean up
12.06. travel back





Support for JCTFEX 2004
Joint Command Task Force Exercise

Camp Roberts travel + Experiment

02.05. Sunday CR

CODE: RHE34

Comfort Suites Jacksonville NC 28546
Hwy 17N, 130 Workshop Lane
910-346-8900
800-228-5150

Camp Roberts 04.05.04 **TERN TRACK TEST**

Take off : 8:56 — 2.4 mw / 1500 ago

Landing : 9:30 — ~ 400 kbps

Solid tracking — no interference detected!

Connectivity aquired:
11:18 TERN → first_TERN_track.txt
11:21 ARIES

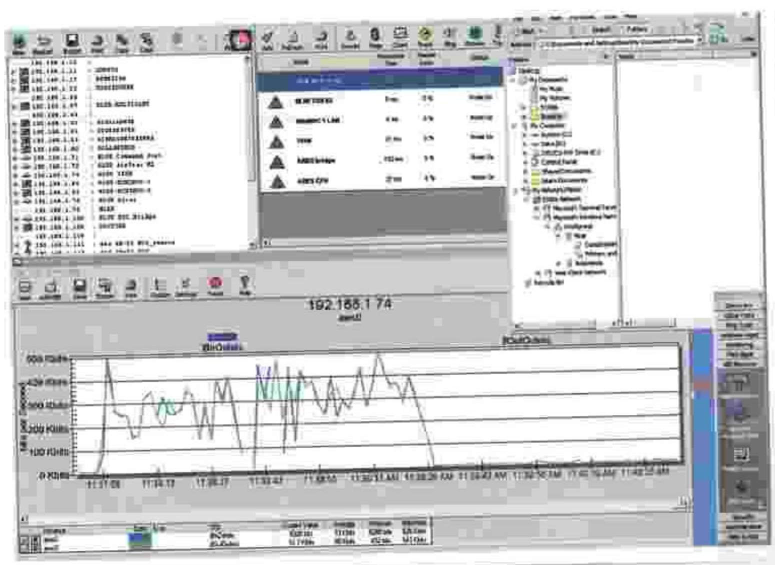
Long Range Log — 05.05.04

I. : 1. 2.852 MB	1:48 sec	=>	211 kbps
2. 2.852 MB	1:28 sec	=>	259 kbps
3. 2.852 MB	1:22 sec	=>	278 kbps

II : ~~1. 6317 MB~~ — 12:15

1 : 953 KB	31 sec	=>	245 kbps
2 : 953 KB	30 sec	=>	254 kbps
3 : 953 KB	36 sec	=>	211 kbps

III : 1. 6317 KB
lost connectivit
→ most probab
→ get stic



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